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An investigation of the effects of image angle on resolution of fine detail screen printing

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AN INVESTIGATION OF THE EFFECTS OF IMAGE ANGLE ON RESOLUTION OF FINE DETAIL SCREEN PRINTING

by
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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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TABLE OF CONTENTS

Page

LIST OF TABLES

Page

Page

LIST OF FIGURES

Page

Page

ABSTRACT

Screen printing, unlike other printing processes, requires ink to be pushed through the image carrier to the substrate. When the mesh threads and their intersections cross the image area, they act as obstructions to the ink flow. In large image areas, the effect of mesh interference is minimal. In fine detail screen printing, mesh interference is a primary cause of poor or inaccurate resolution.

The trend in screen printing has been toward more and finer fine line, halftone and four-color process printing. Researching methods to minimize mesh interference will enable screen printers to gain greater control over the printing process and better utilize technologies currently available for fine detail reproduction.

Previous experiments had shown that the angle of a fine line image relative to the mesh threads will have an effect on resolution quality. This thesis developed a theoretical model for hypothesizing that image angle may also affect resolution in halftone screen printing.

A fine line test image was developed to attempt to reproduce the results of experiments indicating a critical angle exists for fine lines, and to determine if the direction of the squeegee motion is also a factor. Halftone gray scales screened at all of the common four-color and black and white reproduction angles, as well as at the aforementioned hypothesized fine line critical angle, were used to determine if image angle has an effect on reproduceable tonal

range and on the accuracy of resolution in halftone screen printing.

Exposure and squeegee conditions were optimized, and the test images were printed. Data on fine line and halftone resolution was collected and statistically analyzed to determine if image angle had an effect on the resolution.

In all cases, angle was found to have an effect on image resolution. However, no one angle or small range of angles was found to provide significantly better resolution than another.

In the fine line test, it appeared that a relationship does exist between image resolution and the direction of squeegee motion. This was not evident in the halftone resolution data. The halftone data, however, does indicate a relationship exists between loss of percent dot area and tonal range. Further investigation of these factors in screen printing is recommended.

CHAPTER I

INTRODUCTION

Significance and Background of Fine Detail Screen Printing

Quality halftone printing by any process depends heavily on the controlled ability to reproduce gradual tonal shifts from highlight, through middletones, to shadow.

> The fundamental difficulty in screen printing is that the system requires ink (or other depositing substance) to be passed under fluid pressure through a mesh fabric, which disturbs its movement by arranging "flow" and "no flow" areas. These areas correspond to the mesh openings and obstructions formed by threads and their crossings.[1]

The presence of these obstructions presents unique tone reproduction problems in halftone screen printing. Specifically, it is difficult not to lose tonal value in the highlight and middletone areas, and the shadow areas seem to unpredictably gain or lose tonal value.

The dot gain can be due to a combination of factors: the stencil, the substrate surface, mesh elongation, the viscosity of the inks, the squeegee angle, hardness, shape and pressure, prolonged drying time.[2] If carefully controlled, these factors can be minimized. The loss of dot area is a more difficult problem caused by mesh interference and by ink solvents evaporating and leaving ink dried into the open image areas of the mesh.[3]

With the increased acceptance and use of ultra violet (hereafter referred to as "UV") inks, many screen printers have been able to eliminate the latter problem. The lack of solvents in these inks, and their dependence on ultra violet radiation to cure, means they do not dry in the screen during a run or between impressions. Any image area, no matter how small, will stay open and, theoretically, printable with UV inks. Caza writes:

> From this advantage comes the possibility to print with exceptional fineness - lines of 2/1000 or 3/1000 of an inch and halftone printing of 175 or even 200 lines per inch, if the stencilling process in use has a sufficient resolution power.[4]

Indeed, the trend in screen printing has been toward more fine line, halftone and four-color process printing. Capillary action and indirect photostencils, stainless steel and dyed monofilament fabrics, UV inks and curing systems, self-stretching frames, fully automatic presses, and sophisticated measuring equipment have given screen printers greater control over the process and advanced the movement into these fine detail printing markets. For example, four-color process and halftone jobs, such as calendars and posters, that might previously have been printed by offset lithography are being sought and printed by screen printers.[5] There are screen printers currently producing 120, 133, and 150 line halftones. However, the problem of mesh interference with the image area still exists with both fine lines and any halftone ruling, with solvent based and UV systems.

Researching methods to minimize mesh interference will enable screen printers to gain greater control over the printing process and better utilize technologies currently available for fine detail reproduction. Research on mesh interference in tone reproduction (i.e.

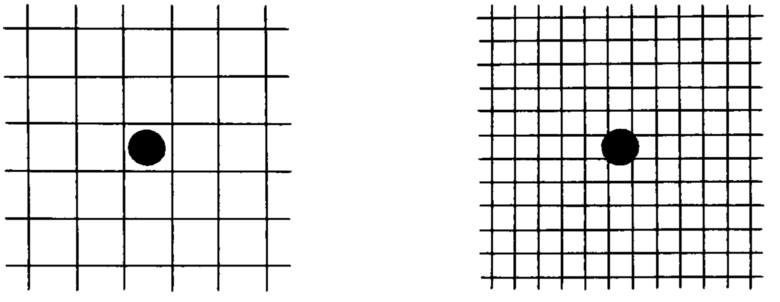
the controlled reproduction of tonal values in an original) will allow for more consistent, predictable results in four-color as well as black and white halftone screen printing. New capabilities in fine detail reproduction will have an effect on established screen printing markets, such as circuit board and point-of-purchase display printing, and on screen printing's expansion into markets currently dominated by the other printing processes.

The Problem

The origin of mesh interference is in the function of the mesh itself. To distinguish between image and non-image areas, the mesh threads support a stencil that prevents ink from flowing through the non-image areas onto the substrate. These threads and their intersections act as obstructions in the open image areas. The degree of obstruction is dependent on the size of the image area, the mesh count (i.e. the number of threads/inch) and the thread diameter. When the image areas are large, this obstruction has a negligable effect, "...as there is then sufficient space, between the walls of the stencil line, for the ink flow to equalize under the threads."[6] In fine detail printing, the reduced area between the stencil edges, and the reduced quantity of ink applied to the substrate, limit the ability of the ink flow to overcome mesh interference at the point of printing. The result is broken, serrated, or wavy lines, broken or non-printing dots.

Therefore, when printing halftone dots or fine lines, it is necessary to minimize the area of mesh-to-image area interaction. This cannot be accomplished by using a lower mesh count. In fact, for greater detailed printing a higher mesh count must be used to decrease the possibility that smaller non-image areas will wash or push through the mesh openings in the stencil preparation or printing processes.

FIGURE 1: Low Mesh Count May Not Support Smaller Non-Image Areas



Lower Mesh Count   Higher Mesh Count

One approach to minimize mesh interference in fine line reproduction is to angle the film positive across the mesh. Scheer writes, "After numerous tests and measurements in copying and printing, an angle of 22.5° was ascertained as being the best for reproduction of fine lines."[7] A forty-five degree angle, he found, caused considerable breaks in the line at thread intersections. An angle from 0° to 10° caused severely serrated edges due to mesh threads interacting along the full length of the line.[8]

The question arises then, if there is a relationship between the angle of a fine line and the mesh for optimum reproduction, is there also a relationship between the angle of a halftone and the mesh? Will changing the screen angle of a halftone change the ability to print middletones, printing dots closely spaced or connected along that angle? If this relationship exists, will there also be less mesh interference and better reproduction in the highlights and shadows? If this relationship exists, how closely related are optimum angles for fine line and halftone screen printing? Is there latitude in these angles or are they critical?

Notes for the Introduction

[1]E. J. Kyle, "Quality Control of the Printed Image - Conclusion," Screen Printing, v. 70, no. 2 (February 1980), p. 74.

[2]Robert Webster, "Screen Printing," Class Notes, June, 1983.

[3]Ibid.

[4]Michael Caza, "The Theory and Practice of UV Screen Printing - Part 2," Technical Guidebook of the Screen Printing Industry, sec. R3, (December 1980), p. 1.

[5]———, "Screen Printers Go for Litho Markets," Printing World, (October 27, 1982), p. 22.

[6]E.J. Kyle, "Is it Screen Printed?," Screen Printing, v. 65, (December 1975), p. 37.

[7]Hans-Gerd Scheer, "Graphic Screen Printing," ZBF Information, (Switzerland: Zurich Bolting Cloth Mfg. Co., Ltd.), sec. F.2.1.3.

[8]Ibid.

CHAPTER II

BACKGROUND THEORY
Tone Reproduction

Definitions

> Tones of a subject are related to the lightness of different surfaces, associated with the intensity of light that any given surface directs to our eyes. Shadow areas are dark, i.e., of low lightness, and contribute little light to the visual image. Areas of high light direct much light to our eyes.[1]

Continuous tone images, such as photographic prints and transparencies, are composed of varying tones that reproduce the gradual tonal shifts present in the subject photographed. When illuminated, the various tones in the photographic image absorb more or less of the available light. The shadow areas appear darker because they absorb more of the light. In the case of a print, this means less light is reflected by the copy from these areas. In the case of a transparency, less light is transmitted through the film.

The ability of a material or given tonal area to transmit light is its "transmittance." This is the ratio of the amount of light transmitted (LT) to the amount of light incident (LI), or light illuminating the material. The ability of a material to reflect light is its "reflectance." It is the ratio of light reflected (LR) to the light incident. The opacity, or the ability of a given material to absorb light is the inverse of the transmittance or the reflectance. It is expressed as LI/LT or LI/LR. The density of a material is a logarithmic measurement of the ability of a given material to absorb light. It is equal, therefore, to the common logarithm of the opacity and is expressed as either

$$\text{Transmission Density} = \log_{10} \frac{LI}{LT}$$

or

$$\text{Reflection Denisty} = \log_{10} \frac{LI}{LR}$$

In printing it is oftentimes necessary to reproduce a continuous tone image. The image may be a photographic print or transparency, or a piece of artwork such as a painting. In screen printing, as in most printing processes, the process itself does not permit the selective variation of ink densities within a given image. Therefore, any solid printed area of the image will have the same tonal value as every other one. Two methods are commonly used in screen printing to overcome this limitation. The first method is to produce separate screens for each tonal value (and/or color), mix the ink to match the desired tone (and/or color), and successively print each screen. This method is most often used by artists who design their work to be screen printed. The second method is to reproduce the image as a halftone. This method is commonly used in all of the major printing processes and is the one considered in this study.

<u>Halftone Dots</u>

A halftone is an image composed of various sized dots of equal density.

> The dots are generally too small to be resolved by the unaided eye when observed from the proper viewing distance....In a given print, the number of dots per unit of area is constant, and different tones are produced by a difference in dot size....

> When an area printed in such a manner is observed, the tone that is perceived by the viewer is synthesized from the combination of printed and unprinted regions. Since these printed and unprinted regions are not generally resolved, such an area is perceived as if it had a single optical reflection coefficient throughout its extent. If a halftone printed area reflects illuminating radiation the same as an area which is uniform, they are perceived as having substantially the same tone.[2]

The actual density of the printed ink film is not varied, but by varying the ratio of printed to unprinted surface area, the size of the printed area can be used to control the amount of light absorbed. Thus the reflection density, and the perceived tonal values, are changed.

The ratio of printed to unprinted surface area is referred to as the "percent dot area." Printed percent dot areas of 65% and up correspond to high reflection densities and simulate the shadow areas of an original. Printed percent dot areas of 5-35% correspond to low reflection densities and simulate the highlight areas of an original. Percent dot areas of 35-65% correspond to reflection densities that represent the mid-tones of the original. Percent dot area is linear, and the shadow dots and highlight dots are inversely proportional to each other.[3] For example a 5% highlight dot has five percent printed area and ninety-five percent unprinted area, whereas a 95% shadow dot has ninety-five percent printed area and five percent unprinted area. On a film negative the reverse is true.

The relationship between percent dot area and reflection density is given by the Yule-Nielsen equation:[4]

$$a = \frac{1-10^{-D_t/n}}{1-10^{-D_s/n}}$$

where "a" equals the percent dot area, $-D_t$ equals the reflection density of the printed halftone, and $-D_s$ equals the solid ink density on the printed press sheet. In this equation, "n" is a compensation value for the internal reflections and light scattering within the paper.

> The value of n is mainly dependent upon the spread function of the paper and the screen frequency of the halftone ruling.... It also depends somewhat on the level of dot area and the solid ink density.[5]

Due to the difficulty of determining correct n values for the many conditions present, this research will adopt an n value of 1.7. Experimentation has shown this to be the most accurate value for a wide variety of conditions.[6] When n equals 1.7, the Yule-Nielsen equation becomes:

$$a = \frac{1-10^{-.6D_t}}{1-10^{-.6D_s}}$$

Because the perceived tonal values on the print depend upon the percent dot areas printed, mesh interference has a large effect on tone reproduction in screen printing. When portions of the halftone dot areas are obscured by the mesh, the printed percent dot areas, and therefore the perceived tonal values, are changed. This effect must be calculated and compensated for in the production of films for halftone screen printing.

It is beyond the scope of this thesis to provide a detailed description of halftone photography. Several good sources of information are noted in the literature review. However, a brief explanation of how a continuous tone image is converted to a halftone is necessary to present a theoretical model for the proposed experiment.

The Halftone Screen

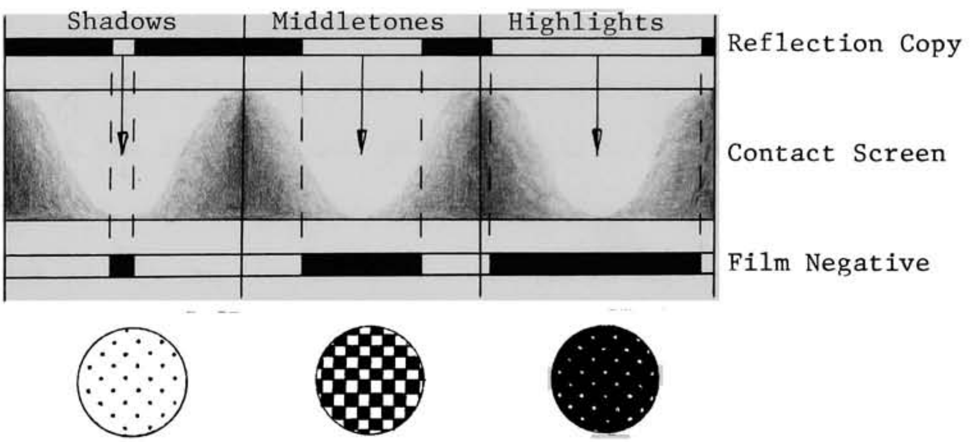
A halftone screen is necessary to convert a continuous tone image to a halftone film. Though there are many types of halftone screens, a contact screen is most often used in black and white halftone reproduction. "A contact screen consists of a pattern of vignetted dot-like apertures. Individual dots vary in density from very light to very dark near the center."[7] The contact screen is positioned over a sheet of high contrast ("lithographic") film on the vacuum back of the reproduction camera.

> This film exhibits a highly critical response to exposure. For exposures less than a particular value, there is no blackening of the emulsion after development, i.e., the optical density of the silver image in the emulsion is low. For any exposure greater than a particular value there is complete blackening.[8]

The film is exposed to the continuous tone original located on the copy board. This is the "main" exposure. The shadow areas of the copy reflect low light intensity capable of penetrating only the least dense areas of the contact screen. As the tones of the original get lighter, they reflect increasing light intensities and penetrate denser areas of the contact screen. The highlight areas of the copy reflect high light intensity that penetrates areas of highest density on the contact screen. The contact screen acts as an optical filter to produce the dot formation. The result is that dots of varying sizes are produced in the developed negatives, and that the size corresponds to the intensity of light reflected by the tonal areas of the copy.

In the shadow areas, the dots are quite small. As the tonal values lighten, the dots grow in size and at that point where the light intensity reflected by the copy is able to penetrate half of the density area on the contact screen, the dots join. This is known as a fifty percent dot. As still more light penetrates the contact screen, the dots continue to merge until only a small white core - representing the densest area of the contact screen - is clear. (Figure 2)

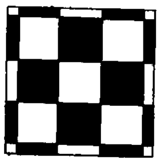
FIGURE 2: Light Penetrates Increasingly Denser Areas of the Contact Screen to Produce Dot Areas on a Film Negative



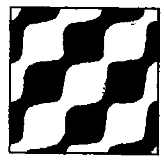
The number of dots per unit area is determined by the frequency of the vignette dot pattern on the contact screen.[9] This is known as the "screen ruling" and is expressed in lines per inch. The screen ruling will also determine the maximum size of the dot in a given percent dot area. Finer halftone rulings (e.g. 100, 120, 133 lines/inch) will produce more and smaller dots with corresponding smaller spaces between them. Coarse screen rulings of 85 lines/inch or less will produce fewer and larger dots with corresponding larger spaces between them. Other variations in contact screens include the orientation (positive or negative), and the color (magenta or gray). The particular contact screen used depends upon the original to be reproduced, and if a black and white halftone or color separation is required.

In addition to these variations, contact screens are manufactured to produce different shaped dots. The two most frequently used contact screen dot shapes are the conventional or "square-dot" and the elliptical dot. A conventional contact screen produces a square dot shape at the fifty percent dot area. When this occurs, the four corners of each dot meet and the dot area appears as a checkerboard pattern. The elliptical contact screen produces dots that are diamond shaped at the fifty percent dot area. In this case, only two corners of the dots join in one direction producing a chain-like pattern. (Figure 3) In the case of the conventional screen, the simultaneous connection at all four corners produces an optical appearance of significant tonal increase at this point. The elliptical screen is seen as producing a more gradual tonal shift and is, therefore, often preferred. With both screens, a line drawn from the base of the screen through the diagonal along which the dots connect will form an angle known as the "screen angle."

FIGURE 3: Fifty Percent Dot Area



Conventional or
"square" dot



Elliptical or
"chain" dot

The traditional screen angle for black and white photography is 45 degrees, because this is the angle at which a screen pattern is least objectionable to the human eye. In four color process printing, four angles must be used, one for each color. The practical angles are limited by the occurance of moire. A moire is an optical disturbance pattern created when two or more frequency patterns or screen angles interact with each other. In printing, it is necessary to minimize this effect, and create an optically pleasing, rather than disruptive, pattern. Halftone dot patterns placed at 30° from each other are generally found to be the least disturbing. For this reason, conventional color separation angles are 45°, 75°, 105° and 90°. (The 90° angle does create a moire, but using it for the yellow printer minimizes this effect.) However, much of the new digitized scanning technology that electronically generates halftone color separations is unable to produce dots at the conventional four-color process angles. In these cases, the separations are made at +18°, -18°, 0° and 45°. To avoid mòire the screen ruling for the halftone at each angle may vary slightly.[10]

Halftone-Mesh Interactions

The difficulties associated with halftone screen printing are primarily related to mesh interference and moire.[11] The moire problem exists because the mesh adds another frequency pattern to that of the halftone. A minor or localized moire is sometimes the cause of "lost" highlight dots. When a moire occurs it is necessary to change either the halftone ruling, the mesh count, or the angle of the image on the mesh. At present there is a "rule of thumb" that suggests a halftone to mesh ratio of 1:(3-5) will most often minimize or eliminate a moire.[12] For example, using this rule of thumb, an 85 line halftone would require a mesh count from 255 to 425 lines per inch. In the past, this ratio limited the halftone ruling printable by the screen process, because it was difficult or impossible to print through an extremely fine mesh with solvent-based inks. With the increased use of UV inks, this has become less of a problem.

The mesh interference problem is still a primary factor in halftone screen printing. Meshes currently available have 15 to 50% of their total surface area as open space. Thus the stencil mounted on the screen can be 50 to 85% obscured by the mesh. The effect, as noted previously, is to alter the tonal value of the halftone. The problem, then, is minimizing the effect of this mesh/image interaction.

Though it is possible to calculate the effect of mesh interference for every mesh, halftone ruling, substrate, ink combination it is not always possible to correct the problem. If, for instance, a tonal value must be represented by a percent dot area of 95%, but the mesh interference is significant enough so that the maximum achievable halftone area on the film will only reproduce as 90% in the print, there is no way to reproduce the tonal value required.

Tone Reproduction Analysis

To compensate for the limitations inherent in halftone reproduction by any printing process, it is necessary to analyze the entire system from the original through the films and final print. The best method for doing this is to quantify the tonal values, as either percent dot area or density, in each step of the process. By comparing one step to the next, with the aid of a graph or graphs, conditions necessary for optimum reproduction with the system in use can be determined.[13] Any necessary adjustments can be made based upon the information and the desired result. It is not the purpose of this thesis to develop specifications for halftone screen printing. However, various graphic representations comparing the percent dot area on the experimental films to percent dot areas on the reproductions will be useful in visualizing the effects of mesh interference in the screen printing system. For this reason, sources on tone reproduction analysis are included in the literature review.

Screen Printing

In screen printing the substrate is printed by pushing ink through the image carrier. Thus the image carrier, or "screen", is an integral part of the printing process. The three components of every screen are the frame, fabric, and stencil. The fabric is stretched and attached to the frame support, and the stencil is adhered to the fabric. Careful selection of screen components can provide control and versatility for a variety of printing conditions and substrates.

The Screen

"The primary function of the screen frame is to act as a support for the screening media."[14] At present both rigid and self-stretching metal frames are used for fine detail screen printing. The self-tensioning frame allows for selective tensioning of the fabric to correct for minor registration inaccuracies during a press run, and for retensioning of the fabric after use.

> An inherent phenomenon of self-stretching frames is the fact that the corners of the fabric are subjected to inconsistent forces which result in unevenness in tension (at the corners) and sometimes tearing.[15]

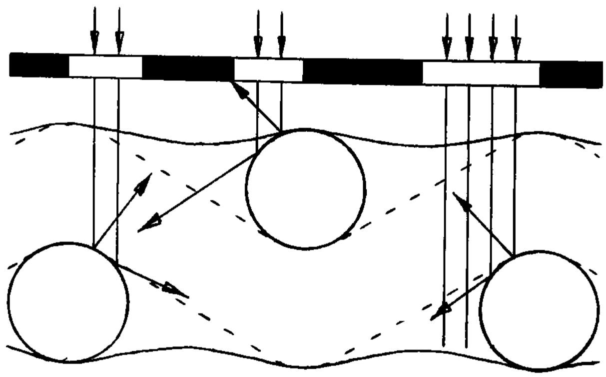
A rigid metal frame is generally lighter than a self-tensioning frame of the same size. For proper tensioning a separate stretching device is needed. With a rigid frame, if tension lessens between press runs the fabric must be removed and replaced.

The screen printing mesh is classified by the type of fabric, and by the dimensional parameters of the filaments and open areas. Each of these mesh characteristics affects the ability to reproduce a particular image on a particular substrate.

Monofilament polyester, metallized polyester, and stainless steel are the most common fabrics used in fine detail reproduction on a flat substrate. When properly tensioned, all provide excellent registration and edge definition capabilities. Stainless steel and metallized polyester offer advantages for static control.[16] Polyester and metallized polyester meshes have better "memory" and, therefore, hold registration more accurately over a long run. "Memory is the ability of a fabric to return to its original position after being deformed by pressure such as that exerted by a squeegee."[17] Stainless steel, once elongated by the printing process, cannot return to its original form.

Dyed polyester fabric is particularly well-suited for small images where direct, direct/indirect, or capillary emulsions are utilized.[18] All of these emulsions are applied to the fabric prior to imaging. The red, orange, gold, or yellow dyes in the fabric absorb the UV portion of the exposing light, thereby minimizing light undercutting during imaging. Stainless steel wire cloth will reflect the light back into the emulsion from the underside and result in image distortion. (Figure 4)

FIGURE 4: Light Reflected off of Mesh Threads Undercuts the Image Area



In high resolution screen printing, the dimensional parameters of the fabric are extremely important. In addition to a fabric with a high mesh count, the optimum mesh has relatively thin fibers and a large percentage of open area. The larger the diameter of the fibers, the more they will interfere with the image.[19] Thread diameters are classified, from thinnest to largest, as S, M, T, and HD. The "S" diameter is, in theory, better. In practice, many screen printers use the heavier "T" fibers, because the "S" diameters are less resistent to abrasion, and therefore less suitable for long runs or re-use.[20] The "M" diameter is not available in many of the mesh counts.

The diameter of the threads has an effect on the percent of open area in the mesh, the fabric thickness, and the width of the mesh opening. The larger the diameter in a particular mesh count, the less open area the mesh will have. A decrease in percent of open area represents a decrease in the area through which ink will be able to flow. In fine detail printing this decrease may represent a substantial portion of the image area to be printed. For this reason, a greater percent of open area is desirable. The width of the mesh opening becomes a factor when the opening is very small and/or the pigment particles in the ink are large. For the ink to be able to pass through the mesh, the rule of thumb is that the mesh opening must be three times the diameter of the largest ink pigment particle.[21]

The thickness of the fabric is the total depth of the weave at the mesh crossings. For a plain weave, used in all of the common meshes for fine detail printing, this is equal to approximately twice the diameter of one thread.[22] The fabric thickness is directly related to the thickness of the printed ink layer. The combination of fabric thickness and stencil thickness directly affects the ink film thickness on the printed substrate in fine detail screen printing.[23] This variable is critical to the final reproduction in high resolution printing. It will effect dot gain or line spread, curing ability with UV systems, color value in four-color process, and the functioning of a circuit in circuit board printing.

There are four photographic stencil systems commercially available for screen printing. All depend on the use of a UV light source to harden the exposed non-image areas through a film positive. The unexposed emulsion is then washed out of the screen, leaving the corresponding image areas open for printing. The direct emulsion system is a liquid emulsion coating applied to the screen before imaging. When dried, it encapsulates the mesh fibers, providing a stencil with high abrasion resistance, and the capability of lasting for very long runs.

This system has two major disadvantages for high resolution screen printing. When it is applied to the screen by hand with a trough-like coating device, it is extremely difficult to ensure consistent stencil thickness over the entire screen area or between several screens. This results in uneven ink deposits on the printed substrate. The second disadvantage is that the emulsion contracts around the fabric threads and their crossings when drying. This produces concavities in the mesh openings. When printing, these areas will not contact the substrate, which allows ink to flow under the stencil edge.[24] Such underflow has a detrimental effect on the edge definition of the image area. In fine detail printing maintaining edge definition is critical. A film stencil system that provides a smooth surface on the underside of the screen is, therefore, generally preferred.

The indirect, direct/indirect, and capillary films are all stencil systems that provide a smooth surface on the printing side, or "job side" of the screen. This facilitates perfect contact with a smooth substrate, and prevents ink underflow. The thickness of these films is either controlled by exposure or by the manufacturing process, thereby permitting predictable and consistent ink film deposit on the substrate. The indirect has the added advantage of being imaged before it is applied to the screen. This can oftentimes be used as a technique for minimizing moire problems. However, since the film is applied to the mesh after imaging, "the indirect stencil lies primarily outside of the fabric weave" and is more easily subject to mechanical wear.[25] Consequently, the system is useful only for short runs.

The direct/indirect and capillary films, similarly to the direct emulsion, are applied to the screen before imaging. As with the direct system, the application procedures for these films result in the film emulsion encapsulating the threads, providing for a stencil with good longevity. However, the presence of a carrier film on the job side during drying ensures no contraction of the emulsion occurs. This film is removed after the stencil is fully dried. The result is a stencil system that combines the longevity of a direct system with the resolution and edge definition of the indirect.[26] The difference between direct/indirect and capillary action films is that the latter is applied to a wet screen and does not require temperature controlled water. Application to the wet screen helps prevent dust particles from interfering with proper adhesion to the screen. The indirect and direct/indirect stencil systems are most often used in fine detail printing.

Printing Variables

Inherent in the screen printing process are a number of interdependent variables related to forcing ink through the screen onto the substrate. Included in these variables are the rheological properties of the ink, the squeegee size, hardness, shape, angle, position, speed and pressure, the flood stroke angle and speed, the image size, and the off-contact gap.

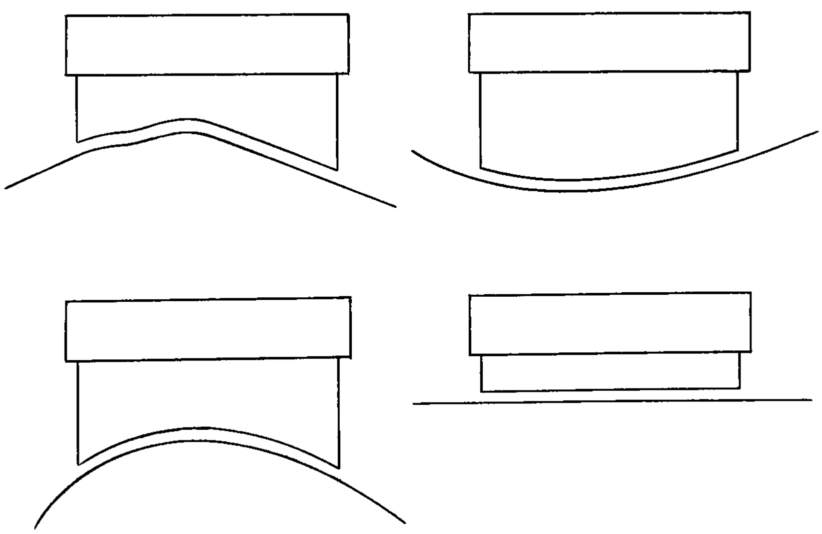
The squeegee provides the initial force for ink transfer. As it travels across the inside of the screen, it pushes ink both across the surface of the mesh and through the image areas. The force with which it does so is determined by the squeegee's angle of attack. The angle of attack is "the slant of the squeegee blade relative to the plane of the mesh."[27] A smaller angle of attack will result in a greater push-through force.[28] Controlling this pressure is fundamental to image resolution accuracy in screen printing. Too much force can result in ink underflow destroying the edge definition and resolution. Too little pressure will not transfer sufficient ink for reproduction.

The squeegee speed also affects the amount of ink transferred to the substrate. "Increased speed changes the rheological behavior of the ink...fast-running machines deposit less ink."[29] To maintain consistent ink film thickness throughout a press run, it is necessary to keep this speed constant.

Squeegee pressure must not only be kept constant, it must also be minimized. Excessive pressure will flex the squeegee blade. Bending the squeegee will change the angle of attack, thereby affecting the ink film thickness and ink underflow. The flexing will be uneven and most pronounced at the edges of the squeegee. Consequently, the angle of attack in these areas will be different from that in the center. The result is that the ink film thickness will vary across the substrate, producing inconsistent image quality.[30]

Required squeegee pressure is partly determined by the hardness (as measured in shore degrees with the use of a durometer) and shape of the squeegee blade. The shape and hardness are, in turn, dependent on the substrate. The squeegee shape should be matched to the substrate so that all points along the squeegee remain parallel to corresponding points on the substrate (Figure 5). This facilitates contact between the screen and substrate during printing. Additionally, in fine detail screen printing the squeegee edge must be sharp. This ensures a clean shearing of the ink at the mesh surface. Any irregularity in the squeegee blade appears as inconsistencies in the print. The durometer will depend upon the surface smoothness and hardness, as well as the type of ink used. Fine detail screen printing on a smooth surface usually requires a durometer of 65-80 shore degrees. A higher durometer squeegee blade will be more resistant to the effects of squeegee pressure.

FIGURE 5: Squeegee Blade Must Be Kept Parallel to the Substrate



The most significant factor in determining correct squeegee pressure is the "off-contact gap." The off-contact gap is the distance between the job side of the screen and the substrate when not actually printing. Normally, as the ink is pushed through the screen it adheres to the mesh threads and the substrate. To fully transfer the ink, a "snap-off" or "peel-off" force must be provided. By leaving a gap between the tensioned screen and the substrate, shortly after the point of printing, the mesh will have a tendency to return to its original non-printing position. As it does so, the cohesive bonds (internal forces that hold the ink together) are broken very close to the mesh threads.[31] Unless the substrate is very absorbent (e.g. textiles), this force is necessary for proper ink transfer.

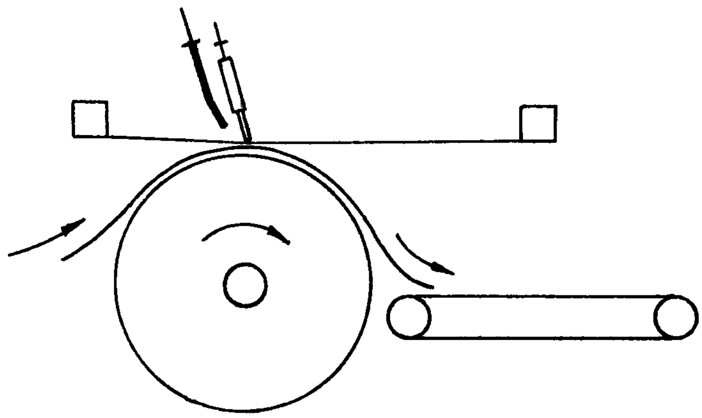
Any off-contact distance requires a pressure, provided by the squeegee, to be exerted on the mesh, stretching it and forcing it into contact with the substrate. This action elongates the mesh, affecting both resolution and registration.

> In the squeegee process, distorting forces affect the screen. They are generated on the one hand by surmounting the off-contact distance (elongation), which is indispensible for a perfect print on a nonabsorbent substrate; on the other hand, the squeegee friction distorts the screen additionally (stretch elongation). The distortion...is not uniform. In the center of the screen is a neutral zone. The nearer the squeegee is to the internal edge of the frame, the larger is the distortion which is greatest in the area of the squeegee ends.[32]

This phenomenon of uneven distortion at different points in the screen requires that the frame size and squeegee length used be carefully matched to the image size. Ideally, the squeegee should be approximately one inch larger than the image on each side so that increased distortion at these points will not affect the image area.[33] The frame size should be large enough for the image to be contained within the center of the screen where there is the least distortion. A large amount of free mesh space should exist between the edges of the frame and image where distortion is greatest. The exact amount of free mesh space required depends upon the registration tolerances for a particular job.

The requirements for minimal off-contact distance in halftone screen printing and four-color work is often a determining factor in the choice of a cylinder or flat-bed press. On a cylinder press the screen is positioned horizontally above the cylinder. (Figure 6) The squeegee is positioned at a point tangential to the cylinder. The screen moves back and forth rather than the squeegee. As the paper is carried on the rotating cylinder, it approaches the point of printing at an angle determined by the cylinder diameter and the tangential position of the squeegee with relation to the cylinder. As it continues past the point of printing, it is still carried by the cylinder and, therefore, leaves the point of printing at an angle also determined by the abovementioned factors. This angle aids in the ink transfer function, and reduces the required off-contact distance. When a cylinder press is used, the squeegee's position above the cylinder must be optimized along with the other squeegee variables.

FIGURE 6: Basic Schematic of a Cylinder Press



After the squeegee stroke is complete, it is necessary to redistribute the ink across the screen. This is accomplished with the flood stroke. The flood bar, a thin piece of metal or plastic, must be carefully positioned so that it moves slightly above or lightly contacts the surface of the mesh. Any pressure exerted by the flood bar on the mesh will result in ink flow through the image areas. The distance from the flood bar to the mesh surface, and the sweep speed of the flood bar, will partially determine the quantity of ink available for transfer during printing. Thus the flood bar affects screen printing resolution. Like the squeegee, the flood bar should be relatively sharp and very smooth. Any roughness or irregularity in the blade will tear the mesh or produce inconsistencies in the print.

Though some printers do not find a flood stroke is necessary, it is particularly important in fine detail screen printing. As was previously noted, fine detail screen printing requires the squeegee pressure be minimized and the angle of attack carefully controlled for optimum reproduction. Without a flood stroke, these two variables must be greatly altered to control the ink distribution and flow. Furthermore, in fine detail screen printing with solvent-based inks, the flood stroke aids in minimizing or eliminating "drying in."

"Drying in" refers to the tendency of solvent-based inks to dry in the image areas of the mesh between print strokes. This is caused by small amounts of ink remaining adhered to the mesh threads after ink transfer to the substrate. The ink that remains is subject to solvent evaporation. At these points, the ink is dried into the mesh, obscuring the openings and preventing the image from printing. The smaller mesh openings characteristic of high mesh count fabrics used in fine detail reproduction plug up relatively quickly. By flooding the mesh, a layer of ink covers these areas, and drying in is less likely to occur. In fine detail screen printing with UV inks, this is not a problem, because the ink "dries" only on exposure to UV radiation.

Another problem with solvent-based inks is the difficulty of controlling ink viscosity during the printing process. The continual exposure of the ink to air evaporates the solvents during the course of the press run. This changes the viscosity of the ink and, therefore, its flow characteristics. A change in rate of flow will alter the amount of ink transferred to the substrate. For this reason, fresh ink with the same viscosity as the original must be added to the screen during the press run (unless the run is very short).

The final stage in the printing process is drying. Air drying is possible with solvent-based inks, but this technique is detrimental to fine detail screen printing. After the image has been transferred to the substrate, the ink remains wet until all of the solvents in it are evaporated out. Thus the ink retains its tendency to flow. The result is the image areas spread, and resolution is lost. The less time between printing and drying, the better the resolution will be. Therefore, a dryer capable of producing heat, which speeds the drying process, should be used. This is not a major problem with UV inks because of their lack of solvent content and the relative speed with which they cure.

Notes for Background Theory

[1]Hollis N. Todd and Richard D. Zakia, Photographic Sensitometry, (New York: Morgan and Morgan), 1969, p. 5.

[2]K.W. Rarey, "Tone Reproduction in Screen Printing," patent number 3,746,540, (October 1965), pp. 6, 7.

[3]D.J. Howe & J.A.C. Yule, "Measurement of Dot Area and Sharpness," TAGA Proceedings, (1954), p. 111.

[4]J.A.C. Yule and W.J.. Neilsen, "The Penetration of Light Into Paper and Its Effect on Halftone Reproduction," TAGA Proceedings, (1951), p. 65.

[5]Milton Pearson, "n Value for General Conditions," TAGA Proceedings, (1980), p. 416.

[6]Ibid., p. 424.

[7]______, The Contact Screen Theory, (Wilmington: E.I. Dupont de Nemours and Company, Inc.), 1982, p. 5.

[8]Rarey, p. 9.

[9]Op. cit., p. 40.

[10]Winrich Gall, "New Directions in Scanner Technology," TAGA Proceedings, (1981), p. 297.

[11]Robert Webster, "Screen Printing," Class Notes, June 1983.

[12]Ibid.

[13]Joseph Noga, "Tone Reproduction," Class Notes, (Winter 1984).

[14]John Bradigan, "Fabrics and Screen Media for Close Tolerance Work," Technical Guidebook of the Screen Printing Industry, sec. D3, (October 1978), p. 2.

[15]John Key, "We've Been Framed," Technical Guidebook of the Screen Printing Industry, sec. E1, (April 1982), p. 6.

[16]Dr. Elmar Messerschmitt, "The Ultimate Screen for Close Tolerance Screen Printing," Technical Guidebook of the Screen Printing Industry, sec. E6, (September 1982), p. 13.

[17]Jeffrey Paul Sauser, "An Investigation of the Effects of Fabric and Stencil on Resolution and Registration in the Screen Printed Circuit Board," (Rochester: unpublished master's thesis), December 1983, p. 11.

[18]Hans-Gerd Scheer, "Importance and Function of the Screen Fabric in Screen Process Printing," (Switzerland: Zurich Bolting Cloth Mfg. Co., Ltd.; distributed by Tobler, Ernst and Traber, Inc., Elmsford, NY), p. 5.

[19]Bradigan, p. 7.

[20]Hans-Gerd Scheer, "Graphic Screen Printing," ZBF Information, (Switzerland: Zurich Bolting Cloth Mfg. Co., Ltd.), sec. F.2.

[21]Bradigan, p. 9.

[22]Hans-Gerd Scheer, "Influence of the Stencil Fabric on the Thickness of Ink Deposit and Consumption of Inks," Technical Guidebook of the Screen Printing Industry, sec. D7, (December 1979), p. 6.

[23]Don Marsden, "Stencil Selection - More than a Direct Approach," Screen Printing, v. 72, no. 3 (March 1982), p. 70.

[24]Ibid., p. 69.

[25]Ibid., p. 80D.

[26]Sauser, p. 14.

[27]Dr. Elmar Messerschmitt, "Rheological Considerations for Screen Printing Inks - Part 2," Screen Printing, v. 72, no. 11, (October 1982), p. 136.

[28]Ibid.

[29]Bradigan, p. 4.

[30]Dr. Elmar Messerschmitt, "Rheological Considerations for Screen Printing Inks - Part 1," Screen Printing, v. 72, no. 10, (September 1982), pp. 63-64.

[31]Messerschmitt, "The Ultimate Screen for Close Tolerance Screen Printing," p. 20.

[32]Bradigan, p. 4.

CHAPTER III

LITERATURE REVIEW

Screen Printing

The technical literature in screen printing is scant. One source, the Technical Guidebook of the Screen Printing Industry,[1] published and distributed by the Screen Printing Association International, is the single most comprehensive resource for technical information. This guidebook is updated regularly with technical articles and panel discussions by screen printers and industry suppliers. The section on "Halftone Photography/Process Color Reproduction"[2] currently contains eleven articles on halftone screen printing. Few of these articles contain actual research information, though many offer suggestions for techniques used in attaining optimum reproduction. Of these, Michel Caza's article, "Screen Printing Fine Line Halftones,"[3] is the most thorough. It discusses the many variables in halftone screen printing and proposes a methodology for optimum printing results.

Also included in this section are two articles on halftone photography addressing the problem of halftone production for screen printing. These articles are "Reproduction Photography" by Daniel Levine,[4] and "Applications and Fundamentals of Halftones for Screen Printing" by Gary Duke.[5]

Though a number of articles mention the problem of mesh interference in halftone screen printing, none provides information on controlled research work investigating how to minimize it. All three of the articles mentioned above suggest partial compensation of the problem can be achieved in the tone reproduction process. None suggest that changing the halftone angle will affect the incidence of mesh interference.

In fact, the only literature that suggest image angle and mesh interference are related is Hans-Gerd Scheer's.[6] Scheer is employed by the Zurick Bolting Cloth Mfg. Co., Ltd. (ZBF) in Switzerland, and has conducted research on minimizing mesh interference in fine line reproduction. His results indicate a 22.5° angle is optimum for fine line reproduction in screen printing though no mention is made of the effect of the direction of the squeegee motion. Also unclear is the degree of tolerance he found in this angle.

Dr. Elmar Messerschmitt has published an article, "The Ultimate Screen for Close Tolerance Screen Printing,"[7] in the SPAI's Technical Guidebook that defines the necessary properties of a screen (frame and mesh) for production of close tolerance screen printing. This article provides many equations for determining image versus frame size, registration variations in a given system, etc.

Tone Reproduction

Sources on reproduction photography are somewhat more plentiful. In addition to the two basic articles mentioned above, Kodak ("Halftone Methods for the Graphic Arts")[8] and DuPont ("The Contact Screen Story")[9] both publish guides outlining the photographic halftone process and describing techniques for optimizing halftone production.

Two articles - "The Penetration of Light Into Paper and Its Effect in Halftone Reproduction" by Yule and Nielsen,[10] and "n Value for General Conditions" by Milton Pearson[11] - in the TAGA Proceedings of 1951 and 1980, respectively, develop and explain the variables involved in, and equations derived for, converting between reflection density and percent dot area. Pearson's work is a modification of Yule's. A good paper for information on measuring percent dot area is "Photometric Measurement of Dot Area" by H. Brent Archer.[12] This paper was originally presented at the TAGA meeting of 1966 and was reprinted as report no. 124 by the Graphic Arts Research Center (now the Technical and Educational Center of the Graphic Arts) at the Rochester Institute of Technology.

The Graphic Arts Research Center at RIT has also published several guides to graphing and analyzing tone reproduction systems. Two of these are "Plotting Tone Reproduction Curves" by J.A.C. Yule,[13] and "RIT Tone Reproduction Test Kit Instructions,"[14] which describes this analysis in conjunction with two test images designed for the purpose. Another article describing the use of these test objects is "A Miniature Test Form for Press Evaluation" by H.B. Archer.[15] This appeared in the TAGA Proceedings of 1978. RIT also published "Instructions for the Use of the RIT 8 x 8 Alphanumeric Resolution Test Target"[16] used in this experiment.

Two other sources describing tone reproduction analysis are Principles of Color Reproduction, J.A.C. Yule,[17] and Photographic Sensitometry by Hollis N. Todd and Richard D. Zakia.[18] Though the first of these books primarily addresses four-color process printing and the later is restricted to photography, both are helpful in explaining the use of the Jones type diagram for analyzing tone reproduction systems. Principles described in each book can be applied to a tone reproduction analysis of a screen printing system.

Notes for Literature Review

[1]———, Technical Guidebook of the Screen Printing Industry, (Fairfax: Screen Printing Association International).

[2]Ibid., sec. C.

[3]Michel Caza, "Screen Printing Fine Line Halftones," Technical Guidebook of the Screen Printing Industry, sec. C10, (June 1983).

[4]Daniel Levine, "Reproduction Photography," Technical Guidebook of the Screen Printing Industry, sec. C1, (March 1978).

[5]Gary Duke, "Applications and Fundamentals of Halftones for Screen Printing," Technical Guidebook of the Screen Printing Industry, sec. C2, (December 1980).

[6]Hans-Gerd Scheer, ZBF Information, (Zurich: Zurich Bolting Cloth Manufacturing Company, Ltd.).

[7]Dr. Elmar Messerschmitt, "The Ultimate Screen for Close Tolerance Screen Printing," Technical Guidebook of the Screen Printing Industry, sec. E6, (September 1982).

[8]———, Halftone Methods for the Graphic Arts, no. Q-3, (Rochester: Eastman Kodak Company), 1982.

[9]———, The Contact Screen Story, (Wilmington: E.I. DuPont de Nemours and Company, Inc.), 1982.

[10]J.A.C. Yule and W.J. Nielsen, "The Penetration of Light Into Paper and Its Effect in Halftone Reproduction," TAGA Proceedings, (Rochester: Technical Association of the Graphic Arts), 1951.

[11]Milton Pearson, "n Value for General Conditions," TAGA Proceedings, (Rochester: Technical Association of the Graphic Arts), 1980.

[12]H. Brent Archer, Photometric Measurement of Dot Area, no. 124, (Rochester: Graphic Arts Research Center), 1978.

[13]J.A.C. Yule, Plotting Tone Reproduction Curves, no. 127, (Rochester: Graphic Arts Research Center).

[14]———, RIT Tone Reproduction Test Kit Instructions, no. 1-226-09, (Rochester, Technical and Educational Center of the Graphic Arts).

[15]H.B. Archer, "A Miniature Test Form for Press Evaluation," TAGA Proceedings, (Rochester: Technical Association of the Graphic Arts), 1978.

[16]———, Instructions for the Use of the RIT 8 x 8 Alphanumeric Resolution Test Object, (Rochester: Graphic Arts Research Center).

[17]J.A.C. Yule, Principles of Color Reproduction, (New York: John Wiley and Sons, Inc.). 1967.

[18]Hollis N. Todd and Richard D. Zakia, Photographic Sensitometry, (New York: Morgan and Morgan), 1969.

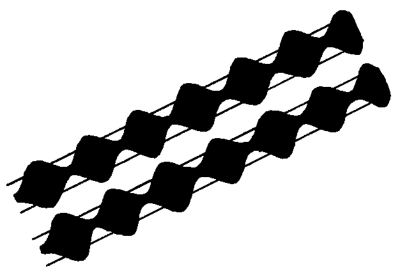
CHAPTER IV

EXPERIMENTAL DESIGN

A Theoretical Model

The theoretical model for this experiment is based on Scheer's finding of a critical angle for optimum fine line reproduction in screen printing.[1] The theoretical model suggests that a fifty percent elliptical dot can be considered a non-ideal fine line: A line with some irregularities, but a line nonetheless (Figure 7). The task in fine line reproduction is to minimize mesh interference and accurately reproduce the line. In other words, reproduce the line with good edge definition, no breaks in the image, and no significant change in image width. The task in halftone reproduction is also to minimize mesh interference and accurately reproduce halftone dots. In this case, "accurately" is to mean no significant change in the tonal value of the image area - i.e., no significant change in percent dot area. If this is so, the same conditions necessary for accurate reproduction in fine line screen printing may also be necessary for accurate reproduction in halftone screen printing.

FIGURE 7: A Theoretical Model



Hypotheses

The following null hypotheses will be tested to determine the validity of this theoretical model.

Hypothesis #1: There is no effect on fine line reproduction due to image angle relative to the mesh threads.

Hypothesis #2: There is no effect on halftone dot reproduction due to image angle relative to the mesh threads.

Hypothesis #3: There is no effect on the reproduceable tonal range due to image angle relative to the mesh threads.

The Test Objects

Two types of test objects were used in this experiment. The first type was used to determine the optimum stencil exposure time and the optimum squeegee settings, and to maintain consistency throughout the press runs. The test objects in this group were the Autotype Exposure Calculator, ladder slur targets, a solid ink density (S.I.D.) patch, and the RIT 8 x 8 Alphanumeric Test Target. The second type was used to test the hypotheses. This group included a fine line resolution test object and halftone gray scales.

The Autotype Exposure Calculator consists of a series of circular test targets composed of line and spaces of varying thicknesses and positioned at varying angles. Below each circular target is a paragraph of type. All of the test targets are identical with the exception of different neutral density filters positioned over four of the five targets. A filter factor for each target is noted on the calculator. All targets are exposed and processed simultaneously. A visual comparison of the targets is made to determine which provides the most detailed resolution and best edge definition. To calculate the correct exposure time for the target chosen, the initial exposure time is multiplied by the filter factor.

This target was used in the original, positive form to determine the correct stencil exposure. It was contacted to a negative for assembly in the test flats. Inclusion in the test flats was to ensure consistency in exposure for all screens.

The Alphanumeric Test Target consists of randomly arranged characters in four displays. Each display is different from another. "Therefore, the observer can be asked to make a judgment under circumstances in which he cannot know in advance what he will be seeing."[2] The characters range in size from .25 lines/mm to 4.5 lines/mm. The directional orientation of the characters varies between displays, thereby allowing for recognition of slur or other directional variation caused by the printing process.

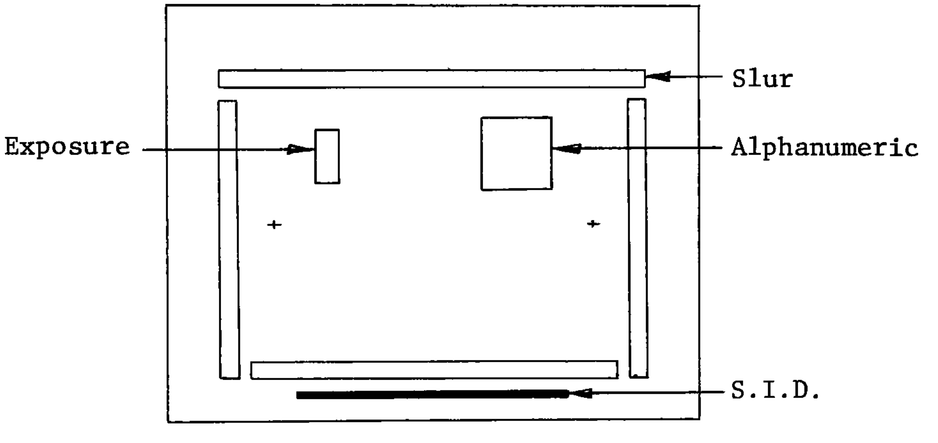
This test target was obtained in negative form and assembled into the test flats. It was used in determining the optimum squeegee settings and to ensure consistency in the exposure and printing of each stencil. The alphanumeric test object was chosen for this purpose, because evaluation of the target is based on character recognition rather than individual lines or halftone dots. This allowed for optimizing the squeegee settings without biasing the results toward one or the other of the two types of experimental images being tested.

The ladder slur targets, consisting of rectangular strips, one-quarter inch wide, surrounded the test objects. These strips were placed on each side of the image area, creating a rectangular image area with outer dimensions of 15 inches by 18 inches. The middle strip in each set contained a series of alternating 4 mil. lines and spaces running perpendicular to the frame's edge. The outer and inner strips, butted against the middle strips had alternating 4 mil. lines and spaces running parallel to the frame's edge. In this way, variation in the printing process could be detected - whether it occurred along the length of the squeegee, at the beginning, middle or end of the print stroke, or in a direction perpendicular or parallel to the squeegee or print stroke. The ladder slur target was obtained as a positive, with all three strips on the film. This positive was contacted four times to produce the negatives for image assembly.

A solid ink density patch running the length of the test image area was positioned below the ladder targets at the end of the print stroke (i.e., on the tail of the press sheet). The density measurements of this area were used as the S.I.D. values in the Yule-Nielsen equation to convert density to dot area during the experimental analysis.

The aforementioned images were assembled on one 17-1/2" x 22-1/2" sheet of Rubilith. A contact was made to produce the positive test film used to determine optimum squeegee settings on the press. The procedure for optimizing these settings is described later in this chapter. Exposure data for all of the contacts is given in Appendix A. Below is a diagram of the positive film (Figure 8).

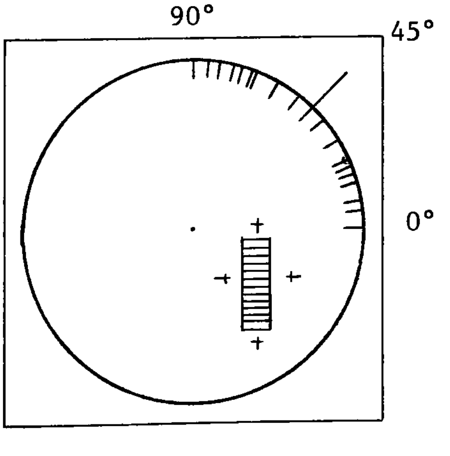
FIGURE 8: Image for Squeegee Test



To test the effect of image angle on halftone reproduction, a Stouffer 12-step relfection gray scale was screened nineteen times. Each time the same film, camera, and 85-line elliptical dot, contact screen were used. An elliptical dot screen was chosen to provide a smoother transition through the middletone areas.[3] The camera was calibrated to place approximately a 98% highlight dot in step one and approximately a 5% shadow dot in step twelve. Exposure data for this procedure is given in Appendix A.

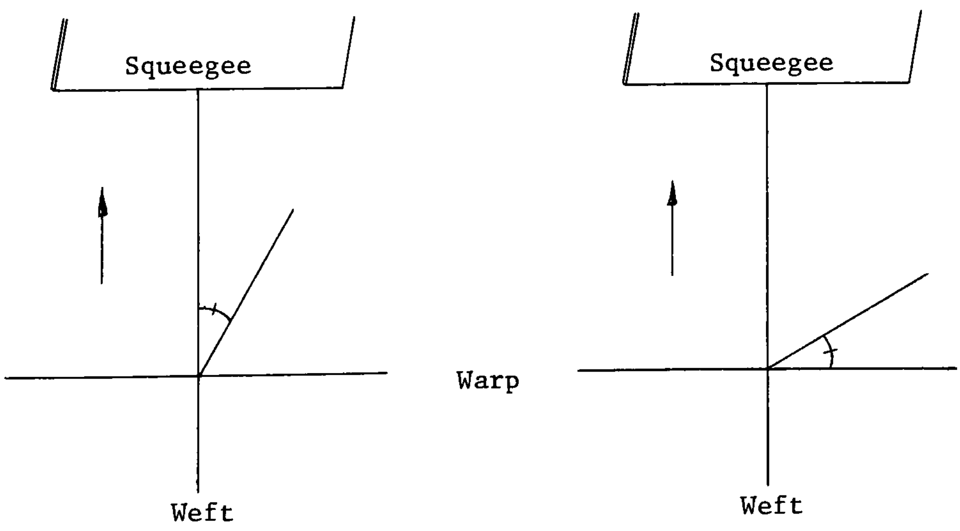
To obtain the angles, the gray scale and four registration marks were mounted on a circular, gray board. The nineteen angles were marked on the board. This, in turn, was mounted by means of a round pin on a black piece of paper with a mark indicating a 45° angle. By rotating the circular board so that each angle marking aligned with the 45° mark on the black backing, the gray scale could be rotated and screened at the various angles (Figure 9). To ensure accuracy, registration marks were also applied to the contact screen. Registration marks from both the copy and the contact screen appeared on the developed film. Hence it was possible to determine the exact position required for 45° on the contact screen to align with 45° on the copy jig. When this position was determined, both the contact screen and the jig were taped in position. Film was inserted under the contact screen without removing the tape. The gray scale was rotated between exposures without untaping the jig from the copy board.

FIGURE 9: Jig for Producing Halftone Gray Scales



The angles used for this experiment were 0°. 6°, 9°, 15°, 18°, 21°, 22.5°, 30°, 39°, 45°, 51°, 60°, 67.5°, 69°, 72°, 75°, 81°, 84°, and 90°. Represented in these angles were all of the common halftone, conventional color separation, direct screen scanner separation and electronic dot generated separation angles, as well as the fine line critical angle cited by Scheer. Additionally, each angle, with the exception of 45°, was replicated with its complimentary angle. This was done to ensure that no assumptions were made about the directional effect of the squeegee motion on the way an angle prints. For example, if by definition the warp threads of the screen fabric ran perpendicular to the direction of squeegee motion and the weft threads ran parallel to the direction of squeegee motion, an image that is angled 20° from the warp threads may reproduce differently than if the same image is angled 20° from the weft threads (Figure 10).

FIGURE 10: Direction of Squeegee Motion in Relation to the Image



The halftone gray scales were exposed in batches of four, and developed in a machine processing unit. Control strips were run through the processor every forty-five minutes to ensure the processing unit did not vary from batch to batch. The film dot areas of each gray scale were then measured with a dot area meter and recorded. The gray scales were randomized (see Appendix A), and stripped up in a single row with one-eighth inch of space separating each one from the next.

A test object to determine the effect of image angle on fine line reproduction was designed and created with the use of a photoplotting device. The image consisted of a series of fine lines of varying thicknesses. Line widths included were 2 mils., 4 mils., 6 mils., and 8 mils. Each series had lines one inch long radiating from the origin, spaced 2° apart. Angles included for each line width ranged from 0° to 90° inclusive, so that each series formed one quadrant of a circle. The series were arranged in a circular pattern with one-eighth inch of space separating each quadrant (Figure 11). As with the halftoned gray scales, this image ensured that no assumptions were made about the directional effects of the squeegee motion on resolution.

The fine line resolution target was originally made as a positive and contacted to a negative. Calibration of the contacting procedures used in image preparation for this experiment was based on comparing the original positive of this test image and of the ladder slur targets to the contacts produced. All were viewed under a 50X microscope with a reticle divided into 1/2 mil. increments. The contact of this image was stripped up in the final test flat along with the halftones. The final test flat, therefore, included all of the abovementioned test images (Figure 12). This was then contacted to produce a single positive film for exposure to the screen.

FIGURE 11: Fine Line Resolution Test Image

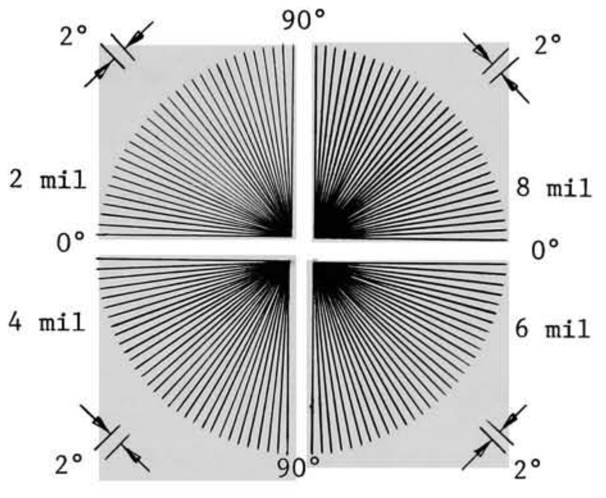
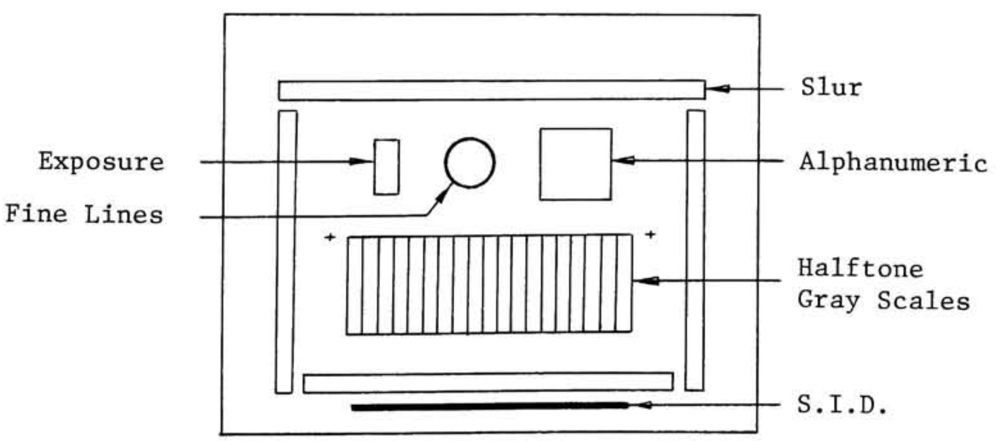


FIGURE 12: Experimental Image



Screen Preparation and Exposure Test

A new, 390T dyed, monofilament, polyester mesh was stretched on a self-tensioning Screen-Tec frame. Mesh parameters before tensioning are summarized in Table 1. The selvage edge of the fabric, which runs straight and in the warp direction, was used as a guide for placing the fabric squarely in the screen. The fabric was stretched to the manufacturer's tension recommendation of 12-13 Newtons/cm. The tension was measured in five places with a tensiometer to ensure consistent tension in the image areas. The mesh was allowed to relax for two hours, before being retensioned. After retensioning, the mesh sat for two days, and then it was retensioned again.

The process of tensioning the mesh, along with the visual method of placing the fabric in the frame, introduces some degree of variability to the screen angle on the frame. This variability is assumed to be random and, since care was taken, relatively small. There is no known method for avoiding such variation which must, therefore, be considered inherent in the printing process.

TABLE 1: Mesh Parameters Before Tensioning

Mesh Count	Mesh Opening	Thread Diameter	Fabric Thickness	Percent Open Area
390	.0013"	.0013"	.0026"	24%

The screen was degreased and an Autotype Capillex 18 stencil was applied to the job side of the mesh while it was still wet. A squeegee was pulled, under pressure, across the stencil area on the inside of the mesh. The screen was then dried with warm air. Once dry, the carrier film was removed. The Autotype Exposure Calculator was placed on the screen, emulsion to emulsion, and the screen was placed in a vacuum frame. Exposure was for 90 seconds to a 4000 watt, metal halide lamp at a distance of 4 feet. The screen was then washed out with 100°F water for six minutes. A water vacuum unit was used to remove as much water as possible from the screen, and the screen was allowed to dry with warm air.

After the screen was dry, it was visually evaluated under a microscope to determine the correct exposure time. Though this examination indicated that exposure times between 45 seconds and 90 seconds all produced equal resolution, a second exposure test proved 45 second to be too little exposure for adequate stencil adhesion to the mesh. Therefore, 60 seconds was chosen as the exposure which provided best adhesion and resolution while minimizing the possibility of image undercutting with increased exposure and light scattering. The exposure data is summarized in Table 2. These conditions were held constant during the remainder of the experiment.

TABLE 2: Exposure and Development Data for Optimum Resolution with Stencil/Mesh Combination

Stencil Type	Exposure Time	Washout Temperature	Washout Time
Autotype Capillex 18	60 Seconds	100°F	6 Minutes

After the stencil was evaluated, the screen was reclaimed, retensioned, degreased, and a new stencil was applied. The first test image film (see Figure 8) was registered on the mesh by means of a jig consisting of a metal bar attached to a table marked with lines running 90° to each other, and parallel and perpendicular to the metal bar. A film positive, identical to the test image was taped onto the table in the position required for correct placement on the mesh. The screen was attached to the metal bar, simulating its position on the press. The bar was then rotated to move the screen out of the way, and the actual positive for the test was visually registered, emulsion up, to the taped positive on the table. The metal bar was rotated again until the screen rested, job side down, on the film positive. The film stuck to the screen by means of tape that had been adhered to the base side of the film. In this manner, it could be ensured that 90° on the test image corresponded closely with 90° on the mesh. A visual postimaging check confirmed this correspondence. As with the stretching of the mesh, however, there is some variability, assumed to be slight, that is built into this method of registration to a screen.

After imaging, the screen was processed, dried, and blocked out. A visual check under magnification was made to confirm the screen was good and the exposure was consistent with the exposure test.

Squeegee Test

The purpose of the squeegee test was to determine the best squeegee hardness and angle for optimum resolution on the press. The press used was a 17-1/2" x 22-1/2" General cylinder press. The speed of the press and the squeegee position were to be kept constant at 1700 impressions/hour and the top of the cylinder, respectively. This point on the cylinder is known as "top dead center" or "TDC". The pressure was to be adjusted first for consistency across the length of the squeegee, and, second, to the minimum pressure required to overcome the off-contact gap and produce a print. Two squeegees of different hardnesses were to be tested at three angles each. Table 3 shows the squeegee angles and durometers used for this test. Both squeegees were made of polyurethane material and were alike in all characteristics except hardness.

TABLE 3: Variables for Squeegee Test

Hardness in Shore Degrees	Position	Pressure	Angles Tested
70	TDC	Minimum Required	70°, 75°, 80°
80	TDC	Minimum Required	70°, 75°, 80°

To ensure that the squeegee position was always at TDC on the cylinder, it was necessary to calibrate the press for this position at each angle. To accomplish this, a metal straight edge was positioned against an inner edge of the impression cylinder gap. The squeegee holder and position bars were set in their neutral or "straight up" positions. The impression cylinder was then rotated until the straight edge was parallel to the squeegee holder. By this means, it was possible to reference a point on the cylinder as top dead center.

The 70 durometer squeegee was then screwed to the metal bar that holds it in place. The angle of the squeegee was adjusted to

80° by means of a calibrated gauge on the press. The entire squeegee assembly was then moved until the printing edge of the squeegee touched the metal rod extending from the cylinder gap. At this point the squeegee printing edge was directly above top dead center on the press for that angle. The position of the squeegee assembly was noted on another gauge on the press. This procedure was repeated for 75° and 70° squeegee angles. A pressure gauge was then used to adjust the straightness along the length of the squeegee, and the squeegee angle was set at 80°, TDC.

The prepared screen with the first test image was placed in the press, and the flood bar was put in position. One ream of 100 pound, 17-1/2" x 22-1/2" Warren Lustro Gloss, a heavily-coated offset paper, was put in the feeder. The press was run to verify the feeding, printing and delivery systems were operating correctly. The ink, a solvent-based black ink (Wiederhold, Sieb-Druckfarben, Schwarz CP-65) was mixed with 25% transparent base (Transpaenpaste CP TP) and 15% retarder (Verzogerer CP D). This mixture was to manufacturer's recommendations for fine detail printing. A solvent-based ink was chosen, because these inks are still more widely used by screen printers than UV inks.[4]

After the ink was poured into the screen, the press was run. During the first few impressions, the squeegee pressure was adjusted to the minimum necessary to print. Ten press sheets were then printed. After printing, they entered an in-line gas drying tunnel via wicket baskets. Turning the drier on was deemed unnecessary, however, because the ink dried extremely quickly. Therefore, though the sheets proceeded through the drier, they actually dried with room temperature air.

The screen was then washed, and the squeegee angle and position were adjusted for a 75° angle. The same procedure as above was followed for this run, and for the run at 70°.

When this series of runs was completed, the screen and squeegee were removed. The 70 durometer squeegee was replaced by an 80 durometer squeegee which was, again, paralleled with a pressure gauge. The screen was put back on the press and the same series of angles was printed as previously described.

The squeegee test yielded 60 press sheets, ten at each of three angles for two squeegees of different hardnesses. To evaluate the results, the press sheets were first separated by durometer, and then by angle. The ten press sheets, in each of six groups were viewed under 5X magnification using a paired comparison method. The observer looked for: maximum resolution attainable, judged by observing the RIT 8 x 8 Alphanumeric Test Target; slur or printing variation, judged by observing the ladder slur targets; and edge definition, judged by the type and lines in the Autotype Exposure Calculator. The paired comparison method for each group yielded one press sheet subjectively determined as the best one from each run with a particular squeegee and angle.

These six press sheets were then compared by the same method, using the same criteria for judgement. Results of this comparison determined that the 80 durometer squeegee, positioned at a 75° angle to the mesh produced the best print. For a ranking of these paired comparisons, see Appendix A. In this press sheet, the paragraph of type in the Autotype Exposure Calculator was very readable and edge definition was good. The slur targets printed evenly with some slur appearing only in those lines printing perpendicular to the direction of squeegee motion. The RIT 8 x 8 Alphanumeric Test Target was very readable to 1.59 lines/mm by the unaided eye, and to 2.24 lines/mm with 5X magnification. Below this resolution, the target printed, but the characters were not clearly identifiable.

The Experiment

Following the squeegee test, the screen, squeegee and flood bar were cleaned. At this time it was noticed that the sheet grippers had poked a hole in the mesh sometime during the press run. Though it was unclear as to why this happened, the suggestion was that at one of the three angles, the squeegee descended onto the grippers at the beginning of the print stroke. Nevertheless, examination of the press runs indicated all of the runs had behaved consistently throughout. It was therefore concluded that the runs had been too short for the squeegee-gripper problem to have had an effect on print results.

A new mesh, with the same parameters as the first, was then stretched, imaged, developed and blocked out. The procedure followed was the same as that followed in preparing the first mesh. The test image used, however, was that shown in Figure 12. After imaging the screen it was noted that moires of various patterns appeared in many of the halftone angles, though not in all steps of any given gray scale. These patterns are described more thoroughly in Appendix C.

The 80 durometer squeegee was remounted in the press and paralleled as previously described. The squeegee angle and position were set at 75° and top dead center, respectively. The screen and flood bar were mounted on the press, and the ink was mixed as before. The same paper and press speed were used as in the squeegee test. During the first few impressions, the squeegee pressure was adjusted, and a visual check was made to confirm that the slur, resolution and exposure were the same as in the squeegee test. The press was then run for 75 impressions. This run length was arbitrarily chosen as a safe limit before the ink viscosity might begin to change, thereby introducing an unwanted variable into the experiment.

Shortly into the run, it was noticed that the squeegee appeared to be printing unevenly in a few spots along its length. The press was stopped, and the screen was washed to eliminate the possibility the unevenness was caused by ink drying into the mesh. The run was then restarted. Though the unevenness appeared again, it was decided to continue with the run. All 75 impressions were printed.

The screen, squeegee and flood bar were cleaned after this run. At that time, it was noticed there were nicks in the squeegee that corresponded to uneven areas in the print. Additionally, it was noticed that the mesh, though not torn through, showed slight impressions where the cylinder grippers had touched it. It was then concluded that the squeegee timing was slightly out of synch, and, therefore, was descending onto the tail end of the grippers rather than immediately past the grippers.

At this point, the press sheets from the first run were carefully examined. With the exception of one small area, it did not appear the squeegee timing had adversely affected the test objects needed to evaluate the hypotheses. Furthermore, it was believed that adequate measurements could be taken without measuring the affected areas. For this reason, it was decided to consider the first run as valid. However, because the affected area seemed to increase after the 44th impression, it was decided to decrease the run length for the experiment from 75 to 40 impressions. Given that the initial run length was arbitrarily chosen, this decreased run length had no significant affect on the experimental analysis.

After this decision was made, the screen was reclaimed. The impression made in the mesh by the grippers during the first run were no longer apparent after reclaiming. Therefore, the mesh was retensioned, and a new stencil was applied. The screen was re-imaged and processed using the same film positive and the same procedures as before. While this screen was being made, the timing on the press was readjusted. Additionally, the squeegee was turned around to provide a smooth, undamaged printing edge. The squeegee was then reparalleled, and the experiment was replicated.

Selection of Samples

After both runs were completed, the press sheets from each run were numbered consecutively from one through 40. Each run was then divided into five parts, with eight consecutive press sheets in each part. This ensured that the full length of the run would be represented in the samples.

A number from one through eight was randomly chosen five times for each press run. The first number chosen determined which press sheet from the first section of the first run would be a sample. The second number determined which press sheet from the second section would be chosen. For example, the second section of each run contained impressions numbered nine through sixteen. The second random number chosen was eight. Therefore, the eighth press sheet in the second section of run two - impression number sixteen - became the second sample in the first run. This was done until five samples from each run had been selected.

Notes for Experimental Design

[1]Hans-Gerd Scheer, "Graphic Screen Printing," ZBF Information, (Switzerland: Zurich Bolting Cloth Mfg. Co., Ltd.), sec. F.2.1.3.

[2]———, Instructions for the Use of the RIT 8 x 8 Alphanumeric Resolution Test Object, (Rochester, New York: Graphic Arts Research Center), p. 3.

[3]Daniel Levine, "Reproduction Photography," Technical Guidebook of the Screen Printing Industry, sec. C1, (March 1978), pp. 11-12.

[4]Robert Webster, "Screen Printing," Class Notes, June 1983.

CHAPTER V

DATA ANALYSIS AND RESULTS

Fine Line Reproduction Data

The test for the effects of image angle on fine line resolution was a subjective test involving thirty observers. The observers were to look at one quadrant of the fine line target on each of the ten sample press sheets, and determine which line was the best. Criteria for judgement were the edge definition, continuity and sharpness of the line. If an observer was unable to choose the single best line, she or he was asked to choose two or three that reproduced equally well and were considered "best". If an observer was still unable to choose, a larger selection or a range of lines was accepted.

The quadrant chosen for viewing was that containing 6 mil. lines. This quadrant contained the lines of smallest width value that reproduced through the full run length of both runs. The quadrants containing 2 mil. and 4 mil. lines both lost some or all of their image area due to ink drying in the mesh during the runs' progression.

Each observer viewed the lines through a binocular microscope at 7X actual size. The microscope first reduced the image to 70 percent of the original size and then enlarged that image 10X. This design permitted observers to view all 46 lines in the quadrant at the same time. All observers were instructed in the method for focusing the microscope, though they were not permitted to change the magnification.

After the observer was instructed in the use of the microscope and the criteria for judgement, she or he was shown each press sheet individually. The press sheets were presented by increasing impression number in run one, followed by increasing impression number in run two. The observer was asked to give the response(s) for each press sheet by line number in the quadrant. All observers were informed which line was number zero and which was number 46. However, the lines themselves were not numbered on the press sheet, and the observer was, therefore, required to count, with the aid of a pointer, to the line she or he wanted to choose. The responses for each observer were then recorded by run and impression number.

After all thirty observers had viewed all ten press sheets, the data was tabulated for each run, and for the sum of the two runs. Two methods of tabulation were used. The first involved a simple count of the frequency with which each line was mentioned by an observer. The second method involved weighting the frequency counts according to the number of times mentioned and the number of other lines indicated for the same press sheet. Thus, if an observer response was for three lines on a given press sheet, each line counted as "1" by the first method, but as only "1/3" by the second. This data is recorded in Appendix B with "Individual Frequency Count" referring to the first method of tabulation, and "Weighted Frequency Count" referring to the second.

The data was then classed into eight groups of five lines each and one group of six lines. Each class, therefore, represented 10°, with one class representing 12°. This last class included the 0°

angle as its sixth angle. The decision to class the frequencies was made to compensate for variation in the stretching and registration procedures (as described in Chapter 4), as well as errors observers may have made in counting lines. Table 4 shows the classed frequency data.

TABLE 4: Classed Frequency Counts for Fine Line Resolution Test

Angles (in degrees)	Individual Frequency Counts			Weighted Frequency Counts		
	Run 1	Run 2	Combined Runs	Run 1	Run 2	Combined Runs
(-1) - 11	12	0	12	8.25	0.00	8.25
11 - 21	6	7	13	5.50	4.13	9.63
21 - 31	9	32	41	5.33	17.18	22.51
31 - 41	9	55	64	7.50	29.14	36.64
41 - 51	46	73	119	38.95	30.63	69.58
51 - 61	7	77	84	6.50	29.10	35.60
61 - 71	9	52	61	5.34	19.57	24.91
71 - 81	4	33	37	3.00	12.00	15.00
81 - 91	81	24	105	67.83	6.50	74.33

The frequency distributions were then graphed for both counting methods, both runs and the combined runs. (Figures 13 - 17) In these graphs, 0° angle corresponds to a line running perpendicular to the direction of the squeegee motion, and a 90° angle corresponds to a line running parallel to the direction of the squeegee motion.

FIGURE 13: Frequency Distribution of Individual Counts for Run 1

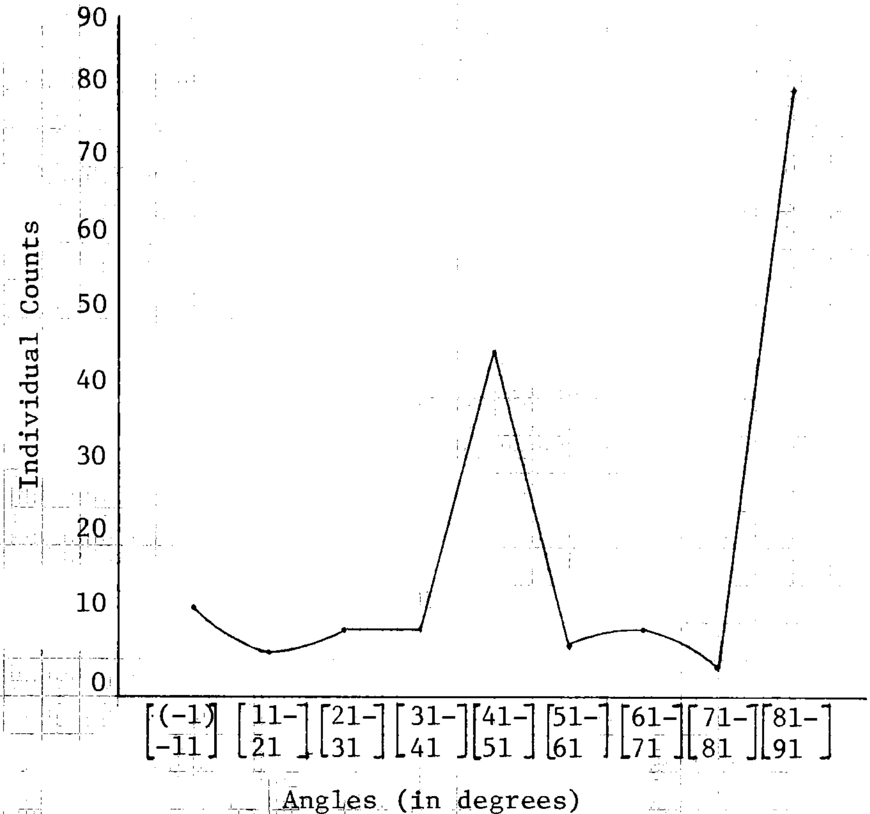


FIGURE 14: Frequency Distribution of Individual Counts for Run 2

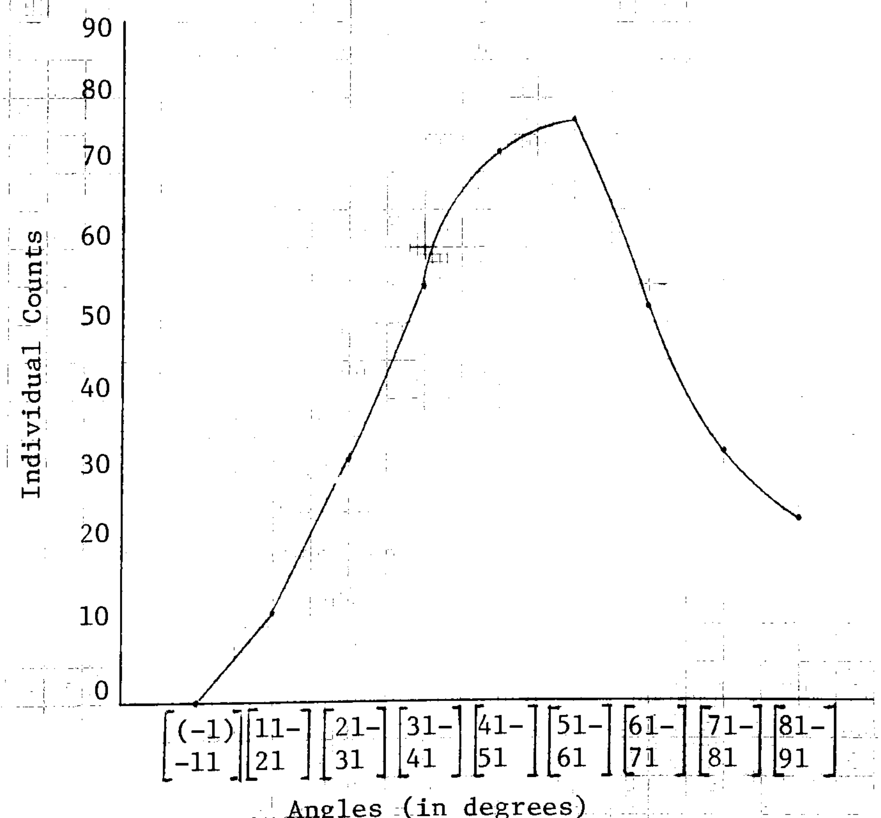


FIGURE 15: Frequency Distribution of Weighted Counts for Run 1

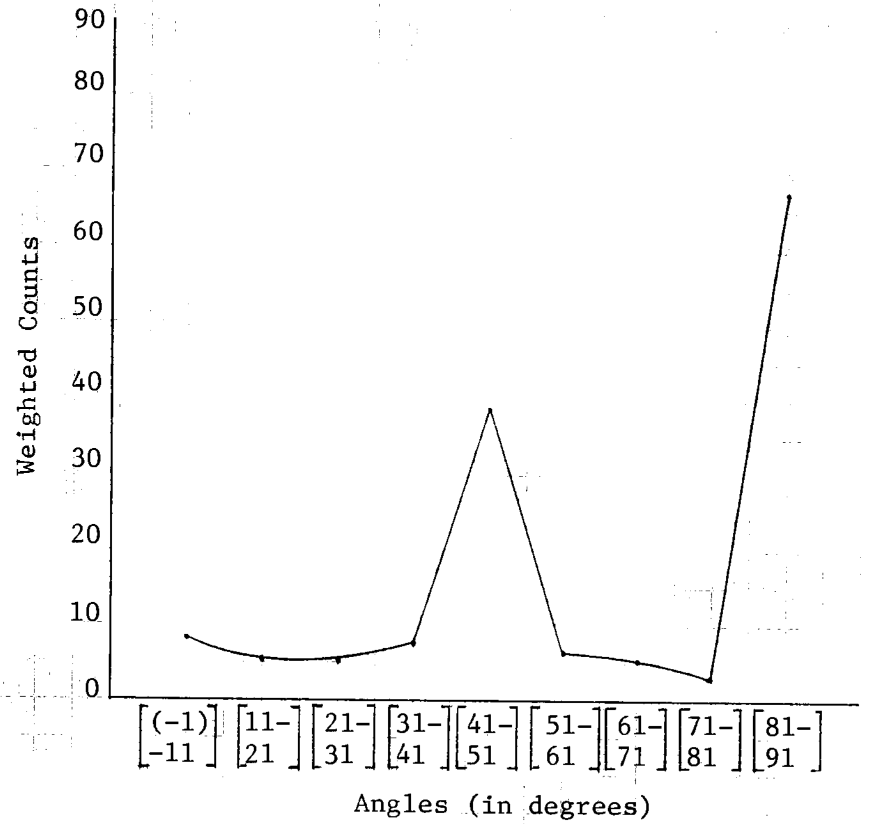


FIGURE 16: Frequency Distribution of Weighted Counts for Run 2

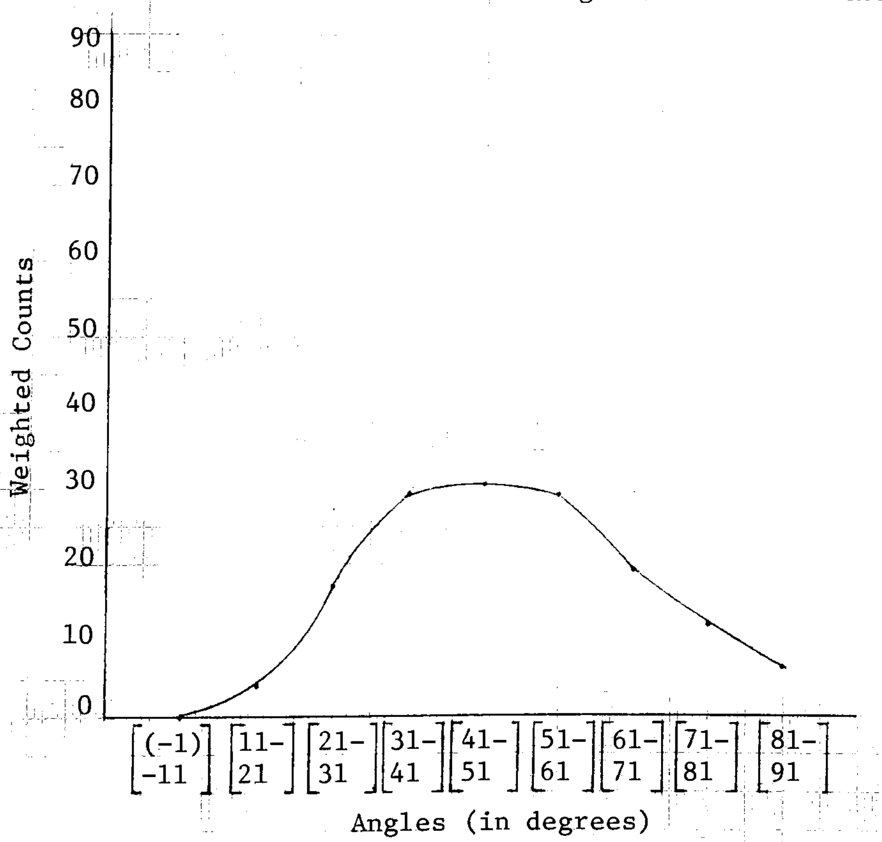
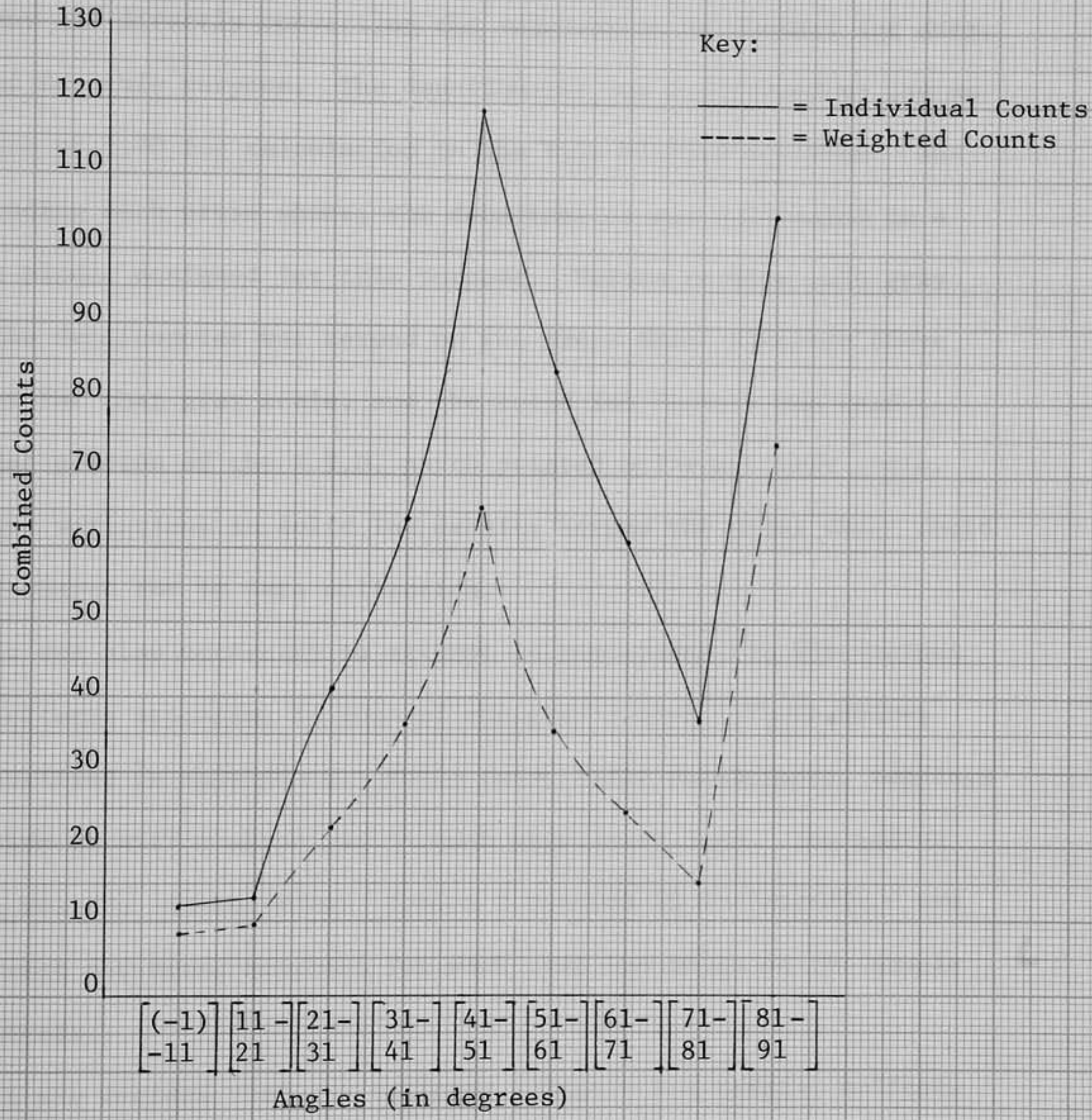


FIGURE 17: Frequency Distribution for Combined Runs



Halftone Reproduction Data

The data collection for halftone reproduction required measuring the percent dot area for each step on each gray scale on all ten sample press sheets. An X-RITE 309 Densitometer, capable of reading reflection copy and directly converting the measurement to percent dot area, was used for this purpose. The densitometer was programmed to use an "n" value of 1.70 for calculation in the Yule-Nielsen equation. Before reading each press sheet, the densitometer was calibrated on a ceramic plaque designed for this purpose. Before reading each gray scale the densitometer was zeroed on the press sheet directly above step one for that gray scale, and the solid ink density was read from that portion of the S.I.D. patch printed below the gray scale. Thus, any variations in solid ink density across the press sheet could be compensated for in data collection.

It was also necessary to attempt to compensate for the various moire patterns appearing in some of the gray scales. These moires are classified in Appendix C. To do this, three densitometer readings were taken at different points in each gray scale step. The median reading was the one recorded. Tables 2 through 20 in Appendix C are the percent dot areas recorded for each step and angle on the sample press sheets.

It was decided that the response variable for testing halftone resolution would be change in percent dot area. This response compensated for variation in the film positive percent dot areas for each gray scale. (Some variation in film positive percent dot areas occurred both in the original halftoning procedure and in the contacting procedure). Therefore, the change in percent dot area from the film positive was calculated for each step and angle on all ten samples. Additionally, the total change for each gray scale step was calculated for both runs, as well as the average change for each step across all ten press sheet samples. This data is recorded in Tables 21 - 39, Appendix C.

To analyze the effect of image angle on halftone resolution it was necessary to perform a Two-Factor Analysis of Variance (ANOVA). The first factor was image angle, and the second factor was tonal value. Tonal value was considered at three levels: highlight, middletone and shadow areas represented by the film positive percent dot areas 4.99-34.55, 34.55-64.55, and 64.55-94.55, respectively. The average change in percent dot area of each run for the film positive steps that corresponded to the three tonal levels was used as the response variable. This eliminated the response variation over the run lengths, a variable that was not intended for study in this experiment.

The mathematical model for a replicated, Two-Factor ANOVA is:

$$X_{ijk} = u + R_i + C_j + (RxC)_{ij} + e_{k(ij)}$$

where: u is the population average of all factors and levels as estimated by $\bar{X}$, the average of all experimental observations; R_i is the effect of factor in rows; C_j is the effect of factor in columns; $(RxC)_{ij}$ is the interaction of the factors; $e_{k(ij)}$ is the random error effect estimated from the replicates; the subscript "i" indicates the total applied to rows; subscript "j" indicates the total applied to columns; and subscript "k" indicates the total is applied to the replicates.[1] The ANOVA table for this experiment appears in Appendix C. The summary table appears below.

TABLE 5: Summary ANOVA for the Effects of Image Angle and Tonal Value on Halftone Resolution

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Critical F Value*
Angle	170.235	18	9.458	1.939	1.797
Tone	799.928	2	399.960	81.975	3.163
Interaction	65.890	36	1.830	.375	1.631
Error	278.089	57	4.879		
Total	1,314.143	113			

*At 0.05 level of significance.

The analysis of variance indicates the variables, image angle and tonal value, have a significant effect on the response at the 95% level of significance. There was no significant interaction. To determine if any particular tonal value(s) and image angle(s) were more significant than the others, multiple range tests were done for both factors. In both tests the average loss in percent dot area for the factor levels was calculated (Appendix C). The averages were arranged in order of decreasing loss, and paired comparisons were made between all levels. Figures 18 and 19 show the results.

FIGURE 18: Results of Multiple Range Test for Factor "Image Angle"

67.5° 51° 22.5° 21° 39° 84° 75° 90° 45° 18° 60° 9° 81° 0° 69° 72° 30° 6° 15°

FIGURE 19: Results of Multiple Range Test for Factor "Tonal Value"

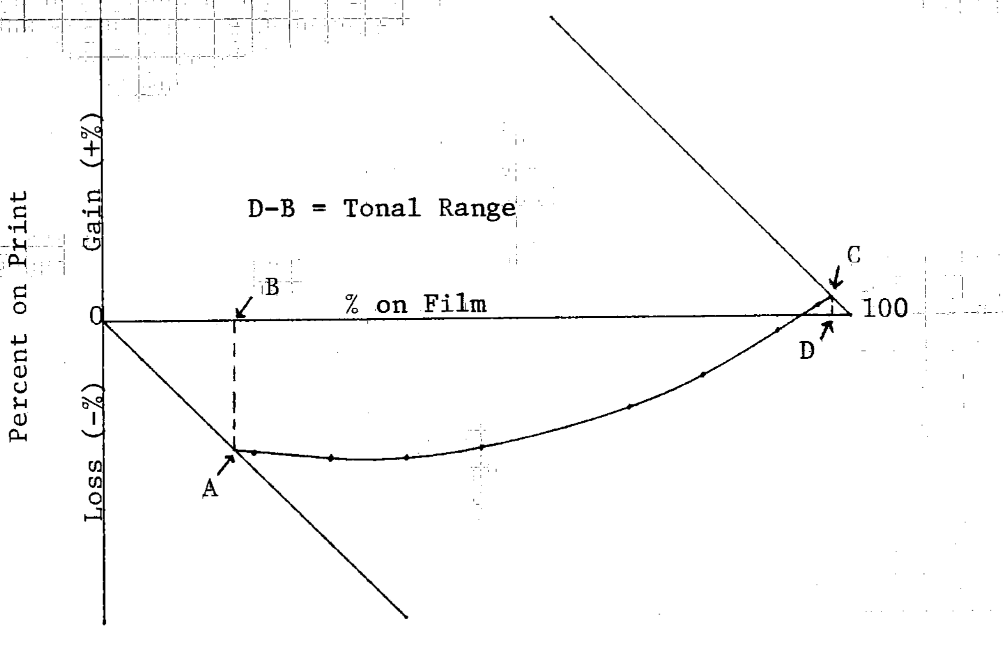
Middletone	Highlight	Shadow
———	———	———

Tonal Range

To determine the effects of image angle on tonal range it was first necessary to construct graphs showing the halftone film positive percent dot area versus the average loss (or gain) in dot area on the prints for each angle. The data for both runs was averaged and used for this purpose. The origin on these graphs represents zero change in percent dot area. The extreme right end of the x-axis represents 100 percent dot area on the film positive. From these two points 45° lines were constructed as shown in Figure 15. The data was then plotted and a curve connecting the points was drawn. It should be noted that change of percent dot area as a function of percent dot area on the original is a non-linear function. For this reason, any curve of the function, created by either using a non-linear regression formula or by connecting data points on a graph, is, necessarily, an estimate.[2]

After the curves were constructed, the points at which the curves intersected with the 45° lines were marked (points A and C on Figure 15). Lines were then drawn parallel to the y-axis from these points until they intersected with the x-axis. Thus it was possible to determine the minimum and maximum values required on the film positive to produce zero and 100 percent dot areas on the prints (points B and D on Figure 20). For example, a curve intersected with the 45° line running from the origin and a perpendicular was drawn to the x-axis. The value on the x-axis was 9.0 percent. A perpendicular drawn from the intersection of the curve with the 45° line extending from the 100 percent dot area, yielded a value on the x-axis of 98.4. By subtracting 98.4 - 9.0, an 89.4 percent dot area was found. This represents the reproduceable tonal range on the film positive.

FIGURE 20: Schematic of Graph Used to Determine Tonal Range (not actual data)



Appendix D contains the graphs constructed to determine tonal ranges for the 19 image angles, as well as the results of the graphing. A multiple range test (Figure 21) was then used to determine if these ranges were significantly different from each other.

FIGURE 21: Results of Multiple Range Test for Tonal Values

81° 45° 84° 72° 6° 90° 39° 60° 9° 69° 30° 15° 0° 67.5° 51° 18° 21° 22.5° 75°

Results of Fine Line Test

The frequency graphs of the fine line resolution test indicate that there is a substantial difference in how this target is reproduced in the two runs. The first run, the one during which the press was slightly out of synchronization, strongly indicates that angles from 40°-50° and from 80°-90° produced lines with the best resolution. While the second run also indicates a peak in resolution around 40°-50°, there was much more of a normal distribution than in the first run. The was particularly evident in Figure 16 where the counts have been weighted.

In run two, this smoothing of the curve by weighting the counts also indicates the difficulty observers had choosing one best line. They were, in this run, inclined to favor a range of angles or several angles as opposed to one specific angle. Though angles from 40°-50° were still favored, all angles from 30°-60° were strong choices. This smoothing is not so evident in run one where angles of 88° and 44° were strongly favored choices.

The differences between the first and second run indicate that observers found the second run to be more consistent than the first. Another notable difference was the lack of any observer choice of an angle from

0°-10° in run two, though this was the third most frequent response in run one. In both runs the angles from 80°-90° were preferred over the angles from 0°-10°. Figure 22 is a 7X macrophotograph of the test image on the screen prepared for run two. It can be seen in this photograph that there does not appear to be a significant difference between lines produced at 0°-10° and those produced at 80°-90°. However, in Figure 23, a 7X macrophotograph of the test target from sample one of run two, this difference, particularly in the edge definition of the lines, is evident. From this it can be concluded that the squeegee's direction of motion has an effect on the resolution of fine lines.

The differences between the two runs are indicated in the graph of the combined data. In these graphs the most noticeable characteristics are the agreement in both runs that 40°-50° angles provided the best resolution, the preference for an angle of 88° in run one, and lack of choice of an angle from 0°-10° in run two.

From this data it must be concluded that image angle does have an effect on fine line resolution. This effect appears to be related to the direction of squeegee motion. The graphs of run one and the combined data would seem to indicate angles 40°-50° produce the best resolution. However, the graph of the weighted counts for run two indicate that angles from 30°-60° provide nearly equal resolution. There does not, therefore, appear to be one particular angle or even a small range of angles that produces the best resolution.

Figure 22: 7X Macrophotograph of Fine Line Test Image on the Screen

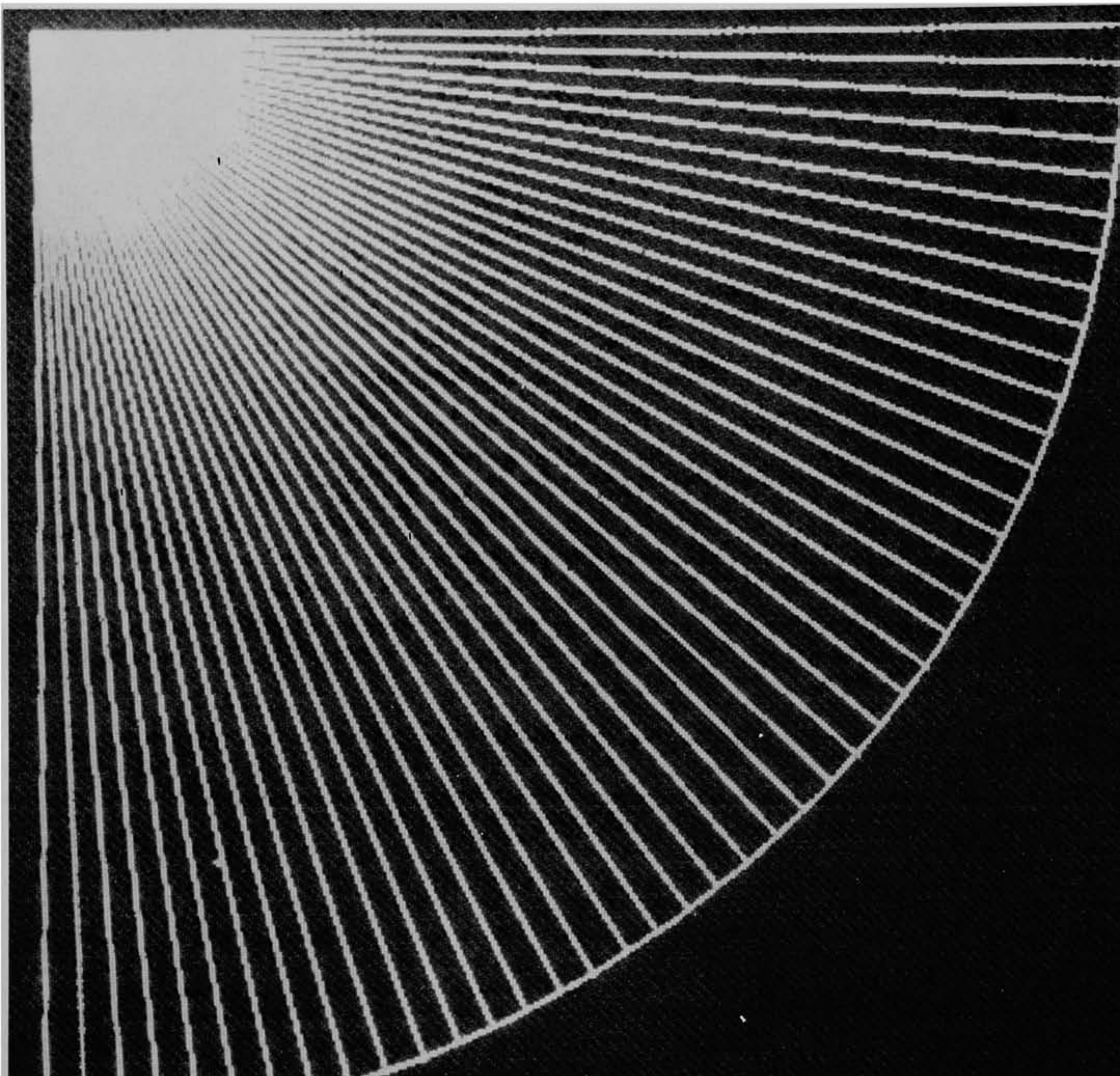
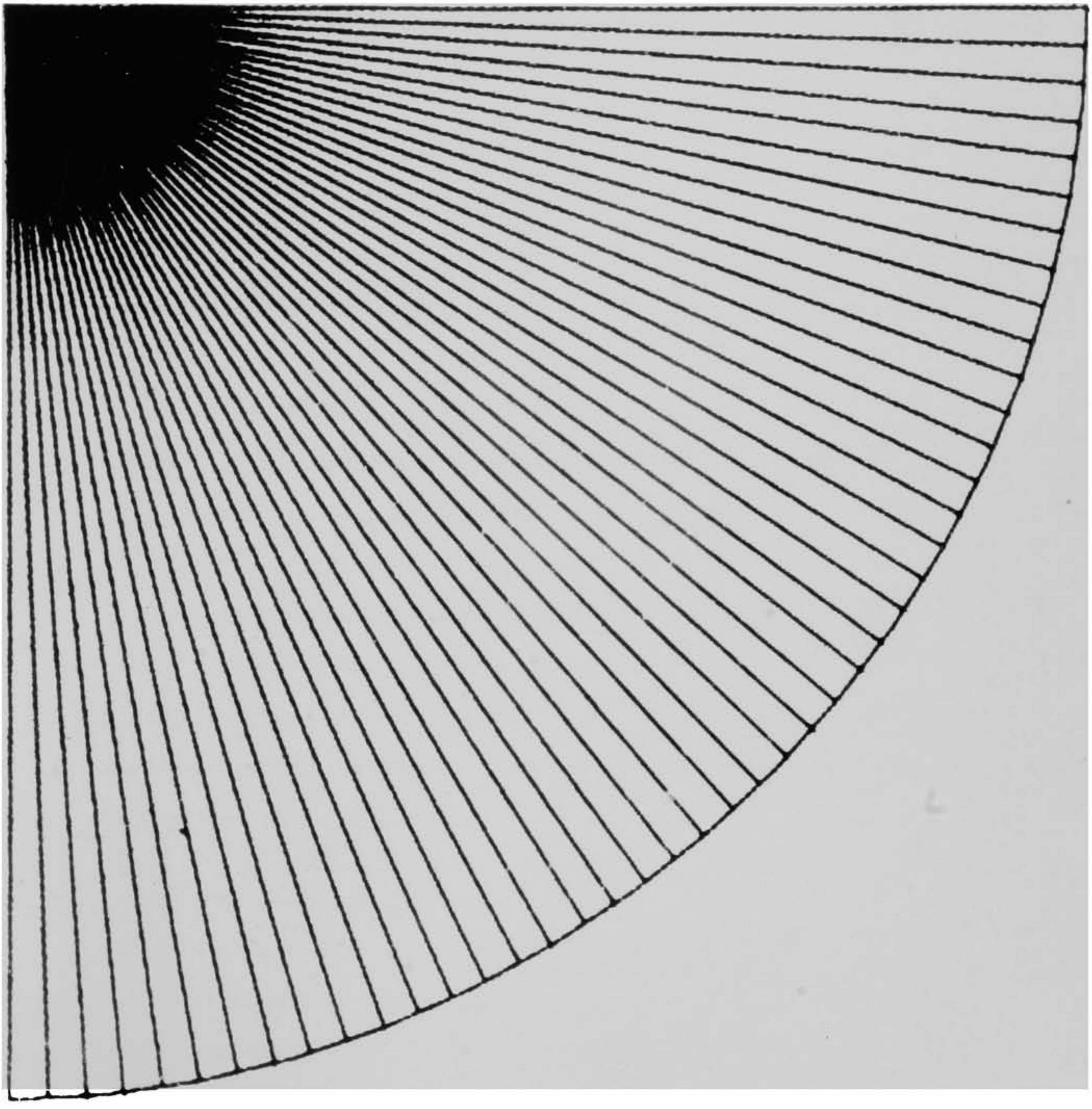


Figure 23: 7X Macrophotograph of Printed Fine Line Test Image.



Results of Halftone Resolution Test

The Two-Factor Analysis of Variance indicated both factors, tonal value and image angle, had a significant effect on halftone resolution. The multiple range test for tonal value indicated that all of the levels - highlights, middletones and shadows - are significantly different from each other. In screen printing halftones, the middletones lose the greatest percent dot area and the shadows lose the least. The multiple range test for image angle, however, indicated that all of the levels were similar. There was no particular angle that reproduced significantly differently from the other, but rather, all of the angles varied slightly from each other producing the slight significance found in the ANOVA.

Figure 24 is a graph of the average loss of percent dot area versus image angle. This graph supports the results of the ANOVA and the multiple range test for image angle. Here it can be seen that, though image angle does have an effect on halftone reproduction, no angle or range of angles produces significantly better resolution. These results agree with the results of the fine line test. However, there appears to be no effect of the squeegee's direction of motion in the reproduction of halftones.

Results of Tonal Range Test

As with halftone resolution, the multiple range test for tonal range indicates no particular angle or range of angles is significantly different from the others. A graph of these results (Figure 25) indicates, again, that image angle does have an effect on tonal range. Furthermore, these results appear to correspond with those for halftone resolution. In general, those angles that produced the greatest tonal range were those that had the least change in percent dot area. However, there were some exceptions to this correspondence. Therefore, this observation should not be considered conclusive.

FIGURE 24: Average Loss of Percent Dot Area as a Factor of Image Angle

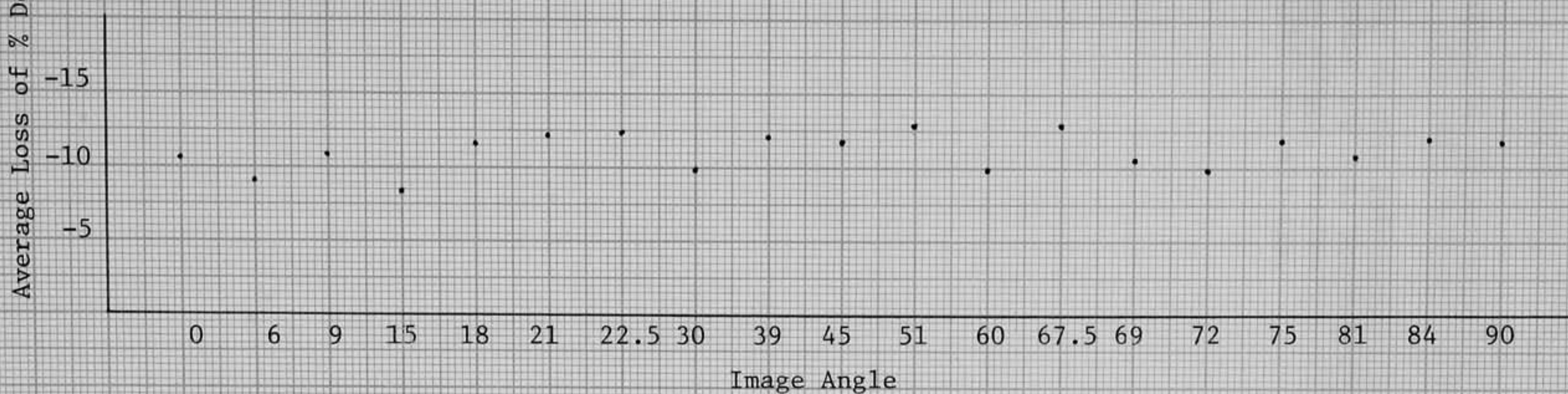
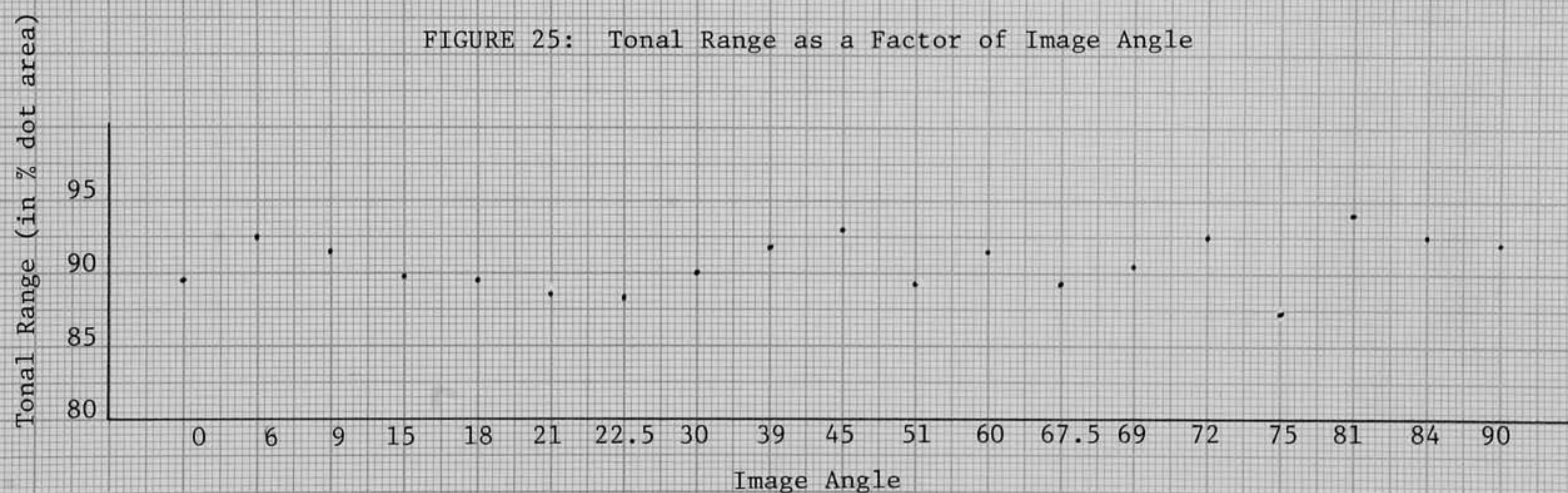


FIGURE 25: Tonal Range as a Factor of Image Angle



Notes for Data Analysis and Results

[1]Albert D. Rickners and Hollis N. Todd, Statistics: An Introduction, (New York: McGraw-Hill Book Company), 1967, pp. 172, 200.

[2]For further information and mathematical models for calculating tonal ranges see J.A. Stephen Viggiano, "The GRL* Dot Gain Model," TAGA Proceedings, (Rochester: Technical Association of the Graphic Arts), 1983, pp. 423-439.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The results from this experiment indicate that image angle does have an effect on resolution in fine detail screen printing. However, the data from this experiment does not show that any particular angle, or small range of angles provides significantly better resolution than another. Therefore, though the null hypotheses must be rejected, this should not be construed as support for the theory of a critical angle in fine line resolution.

There does appear to be a relationship between fine line resolution and the direction of squeegee motion. The exact nature of this relationship is unclear. From the results of this experiment it might be hypothesized that a continuous image, such as a fine line, should contain a substantial vector relationship to both the direction of squeegee motion and the direction of squeegee for optimum resolution. An experiment addressing this hypothesis would be informative and important to the circuit board industry as well as other screen printers involved in fine line reproduction.

No relationship appears to exist between the direction of squeegee motion and halftone resolution. This may be an indication that the screen printing process has a different effect on the production of continuous and discontinuous images. Further research in this area is also recommended.

A relationship does appear to exist between loss of percent dot area and reproduceable tonal range in halftone screen printing. Research in this area may provide screen printers with a valuable quality control tool for the production of halftone film positives and the monitoring of press runs and printing conditions.

Though the squeegee test was conducted as a method for optimizing the squeegee angle and position for the main experiment, the paired comparison test indicated a definite pattern to these press sheets (See Appendix A). Specifically, it was noticed that at 70° and 75° angles, durometer was more significant than angle to a ranking of print quality. However, the difference in print quality between the 75° and 80° angles was larger, and, in this case, appeared to be more important to the printed results than durometer. Again, further investigation is recommended.

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APPENDIX A

Exposure and Development Data for Halftone Gray Scale Negatives

Camera: Langstem Monotype
Magnification: 100%
Aperture: f/11
Filter: Wratten 2B
Film: 3M QA-4, 8" x 10"
Main Exposure: 25 Units
Flash Exposure: 16 Units

Contact Screen: Polichrome
85 Lines/Inch
Gray, Negative
Elliptical Dot

Screen Range: 1.09 (density)

Processor: Fuji Automatic FG25L
Chemistry: Lithographic
Time: 1:45
Temperature: 80°

APPENDIX A

Exposure and Development Data for Test Image Contacts

Point Light Source
Film: 3M QA-4, 16" x 20"
Exposure: 6 seconds, 8 volts

Processor: Log E Automatic
Chemistry: Lithographic
Time: 90 seconds
Temperature: 80°

APPENDIX A

Exposure and Development Data for Experimental Test Flat

Point Light Source
Film: 3M QA-4, 16" x 20"
Exposure: 7 seconds, 8 volts

Processor: Fuji Automatic FG25L
Chemistry: Lithographic
Time: 1:45
Temperature: 80°

APPENDIX A

TABLE A-1

Randomization of Gray Scales on Test Flat

Order	Image Angle (in degrees)
1	45
2	72
3	81
4	15
5	6
6	69
7	60
8	0
9	39
10	22.5
11	67.5
12	51
13	75
14	9
15	90
16	30
17	84
18	18
19	21

APPENDIX A

TABLE A-2

Paired Comparison Rankings for Squeegee Test

Rank	Hardness (in degrees)	Squeegee Angle
1	80	75°
2	80	70°
3	70	75°
4	70	70°
5	80	80°
6	70	80°

APPENDIX B

TABLE B-1

Frequency Counts for Fine Line Resolution Test

Angle (in degrees)	Individual Frequency Counts Run 1	Run 2	Combined Runs	Weighted Frequency Counts Run 1	Run 2	Combined Runs
0	8	0	8	5.75	0.00	5.75
2	3	0	3	1.50	0.00	1.50
4	0	0	0	0.00	0.00	0.00
6	1	0	1	1.00	0.00	1.00
8	0	0	0	0.00	0.00	0.00
10	0	0	0	0.00	0.00	0.00
12	0	2	2	0.00	2.00	2.00
14	3	1	4	3.00	0.50	3.50
16	0	1	1	0.00	0.50	0.50
18	1	2	3	1.00	1.00	2.00
20	2	1	3	1.50	0.13	1.63
22	4	2	5	2.33	2.00	4.33
24	1	4	5	0.33	1.55	1.88
26	2	7	9	2.67	3.34	6.01
28	2	10	12	0.00	4.40	4.40
30	0	9	9	0.00	5.89	5.89
32	2	10	12	1.50	4.65	6.15
34	1	12	13	1.00	6.90	7.90
36	0	14	14	0.00	9.28	9.28
38	2	9	11	1.50	3.01	4.51
40	4	10	14	3.50	5.30	8.80
42	9	14	23	7.75	7.29	15.04
44	26	12	38	21.58	3.98	25.56
46	10	16	26	8.62	7.28	15.90
48	0	16	16	0.00	6.36	6.36
50	1	15	16	1.00	5.72	6.72
52	0	10	10	0.00	2.76	2.76
54	0	12	12	0.00	3.29	3.29
56	2	11	13	2.00	2.81	4.81
58	1	17	18	1.00	8.38	9.38
60	4	27	31	3.50	11.86	15.36
62	3	16	19	2.33	5.89	8.22
64	2	10	12	0.67	2.88	3.55
66	1	10	11	1.00	4.69	5.69
68	2	5	7	1.17	1.63	2.80
70	1	11	12	0.17	4.48	4.65
72	1	12	13	1.00	6.04	7.04
74	0	8	8	0.00	3.62	3.62
76	1	7	8	1.00	1.99	2.99

APPENDIX B

TABLE B-1 Continued

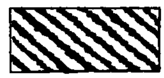
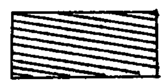
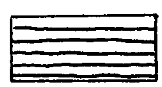
Frequency Counts for Fine Line Resolution Test

Angle (in degrees)	Individual Frequency Counts Run 1	Individual Frequency Counts Run 2	Individual Frequency Counts Combined Runs	Weighted Frequency Counts Run 1	Weighted Frequency Counts Run 2	Weighted Frequency Counts Combined Runs
78	1	2	3	1.00	0.08	1.08
80	1	4	5	0.00	0.27	0.27
82	3	3	6	2.20	0.13	2.33
84	2	4	6	0.45	1.13	1.58
86	2	4	6	0.45	1.13	1.58
88	70	4	74	57.78	0.62	58.40
90	4	9	13	6.95	3.49	10.44

[redacted]

APPENDIX C

TABLE C-1: Classification of Moires in Halftone Gray Scales

Angle(s) Moire Appeared in	Description of Moire	Pictorial Representation
0°, All Steps 90°, Steps 7-9	Crossed lines of greater density creating diamond shaped patches of lighter density.	
6°, Steps 5-8	Jagged diagonal lines of greater density running from top left corner of step at ≈45° angle. Most apparent in Step 6, barely visible in other steps.	
9°, Steps 5-10 15°, Steps 5-9	Smooth diagonal lines of equal widths for greater and lesser densities. Running from top right to left at ≈60° angle.	
21°, Steps 8 & 9 22.5°, Steps 9 & 10	Smooth lines of greater density running from top left to right at ≈10° angle.	
30°, Step 8 60°, Step 7	Very faint diagonal lines of greater density running from top left to right at ≈60° angle.	
39°, Steps 4-9 75°, Step 5	Very faint diagonal lines of greater density running from top left to right at ≈30° angle.	
45°	Slightly wavy horizontal lines; lines of greater density thinner than lines of lesser density.	
51°, Steps 5-7, 9 84°, Steps 7-9	Lines of greater density running from top right to left at ≈10° angle.	

APPENDIX C

TABLE C-1 Continued

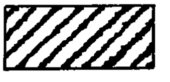
Angle(s) Moire Appeared In	Description of Moire	Pictorial Representation
67.5°, Steps 5-8 69°, Step 6	Smooth diagonal lines of equal widths for greater and lesser densities running from top left to right at ≈60° angle (jagged lines in 69° angle, Step 6).	
75°, Steps 7-9	Diagonal lines of greater density running from top right to left at ≈30° angle.	
81°, Steps 5 & 7	Jagged diagonal lines of greater density running from top right corner of Step at ≈45° angle.	

TABLE C-2

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 0° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
.5	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2
13.1	2	9.9	.2	0.0	0.0	.2	6.0	3.4	3.1	0.0	0.0
27.6	3	17.5	14.1	14.3	12.8	12.1	15.7	12.6	11.7	12.8	12.9
44.4	4	32.7	31.1	32.2	29.8	31.8	25.0	27.6	28.0	25.6	25.8
59.4	5	52.1	52.3	51.5	52.1	47.7	43.2	47.3	45.0	48.1	46.7
71.7	6	58.8	66.1	64.6	64.2	57.7	57.1	60.4	58.7	60.2	59.1
81.9	7	72.7	78.0	76.1	77.5	74.7	77.2	76.9	73.9	73.8	73.6
88.2	8	82.4	86.6	85.3	84.1	81.8	81.4	83.0	81.6	81.0	82.1
93.2	9	88.3	92.7	91.7	91.4	89.5	90.0	89.6	89.9	90.2	90.1
96.1	10	94.6	96.6	97.0	96.6	96.0	93.8	95.1	94.2	95.1	94.9
98.6	11	99.2	99.5	99.4	98.7	99.5	99.6	99.2	99.7	99.6	99.6
99.3	12	99.7	100.0	99.9	99.6	99.8	99.9	99.8	99.9	100.0	100.0
	S.I.D.	1.99	1.98	1.98	1.96	1.99	1.94	1.95	1.94	1.94	1.93

*By impression number.

Appendix C

TABLE C-3

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 6° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
0.0	1	.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.9	2	2.4	0.0	0.0	0.0	0.0	3.4	.7	0.0	0.0	.2
22.2	3	16.5	7.8	6.7	6.5	5.1	14.2	10.6	9.5	9.0	9.9
39.0	4	29.8	26.6	27.5	28.1	28.3	23.1	22.2	23.2	23.6	23.2
54.7	5	46.5	54.8	52.3	53.5	46.8	40.4	42.5	42.1	41.6	43.6
70.8	6	54.2	63.3	61.5	60.3	59.8	58.0	60.7	60.2	58.4	58.9
83.2	7	70.9	78.0	76.4	76.4	74.5	75.6	76.5	75.7	75.7	75.7
89.6	8	80.4	86.5	85.4	85.2	83.8	84.8	85.7	84.1	84.3	84.4
93.6	9	88.4	91.8	91.2	90.7	88.3	90.6	90.7	90.7	89.8	90.7
96.8	10	96.4	96.8	97.1	96.0	96.3	97.3	97.0	97.2	97.1	97.1
98.2	11	98.9	98.8	99.0	97.8	99.2	99.5	99.2	99.2	98.4	99.7
99.2	12	100.0	100.0	99.8	100.0	100.0	99.8	99.6	99.6	99.7	100.0
	S.I.D.	1.96	1.98	1.98	1.96	1.96	1.94	1.96	1.95	1.96	1.95

*By impression number.

Appendix C

TABLE C-4

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 9° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
0.0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.7	2	0.0	0.0	0.0	0.0	0.0	.2	0.0	0.0	.2	0.0
18.7	3	14.0	5.5	5.3	3.4	2.4	9.3	7.9	6.7	4.2	4.6
36.7	4	27.6	24.6	24.9	27.9	27.5	19.5	19.0	18.5	18.4	19.8
55.4	5	43.7	47.2	49.5	47.4	44.7	40.3	38.6	39.7	40.9	40.2
72.1	6	56.3	60.9	60.8	58.8	56.2	61.5	60.1	60.5	61.2	58.7
84.5	7	72.9	78.2	75.7	75.0	73.3	75.6	76.1	76.0	76.8	75.0
90.3	8	81.4	87.3	86.0	84.9	83.1	86.5	87.3	85.4	86.4	85.7
94.2	9	88.3	93.1	92.2	91.6	89.5	92.0	92.3	92.1	92.2	91.5
97.3	10	96.8	97.4	97.3	97.5	96.5	97.6	98.4	98.1	97.8	98.0
98.9	11	99.6	99.7	100.0	99.8	99.6	100.0	100.0	100.0	100.0	100.0
99.3	12	99.9	99.8	100.0	99.9	100.0	99.7	99.7	99.8	99.9	100.0
	S.I.D.	1.97	1.99	1.97	1.97	1.97	1.94	1.94	1.94	1.94	1.96

*By impression number.

TABLE C-5

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 15° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
.5	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.0	2	8.8	.2	0.0	0.0	0.0	11.7	6.0	4.6	3.4	2.4
25.8	3	19.6	14.1	15.6	14.1	12.8	18.6	16.2	15.4	17.9	16.3
41.8	4	31.7	32.9	34.3	36.9	32.0	29.7	27.7	28.7	29.1	29.7
56.2	5	47.6	55.1	55.4	53.6	49.6	45.1	43.2	43.8	45.1	44.3
69.4	6	55.1	64.9	64.5	64.1	58.2	57.5	57.6	57.3	57.5	57.4
81.0	7	69.4	76.0	75.1	75.1	72.0	72.7	73.8	72.5	72.6	72.5
88.0	8	79.2	84.8	84.5	83.5	81.5	82.9	82.2	81.8	81.2	82.3
92.4	9	86.5	91.6	90.3	89.9	88.1	89.6	90.4	89.9	90.8	90.3
96.3	10	93.9	96.2	95.7	96.1	95.4	95.3	96.5	95.9	95.5	96.3
98.0	11	98.2	99.0	98.7	98.6	98.4	99.3	99.6	98.9	99.1	99.8
99.0	12	99.8	99.5	99.7	99.9	99.7	99.6	99.6	99.5	100.0	100.0
	S.I.D.	1.96	1.99	2.00	1.98	1.98	1.94	1.97	1.96	1.96	1.94

*By impression number.

Appendix C

TABLE C-6

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 18° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
3.9	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.5	2	8.3	.9	1.2	.9	0.0	5.5	4.1	2.4	.4	0.0
26.1	3	19.0	14.7	14.4	16.6	14.9	12.6	11.4	10.8	11.7	12.2
41.4	4	28.9	25.1	27.5	29.2	29.7	24.1	23.7	23.6	23.0	22.4
56.1	5	41.0	48.1	46.1	46.0	43.8	40.6	40.6	40.1	41.1	41.8
71.0	6	52.5	60.5	61.3	58.8	57.0	56.4	57.9	58.2	58.3	58.4
82.6	7	68.8	74.5	75.6	74.0	72.4	73.9	74.5	72.8	74.3	73.9
89.3	8	78.8	83.1	83.0	82.2	82.5	84.9	82.9	82.9	83.3	84.0
93.6	9	85.1	91.1	90.4	90.0	87.6	91.4	90.5	89.3	90.6	90.5
96.2	10	92.2	96.4	95.6	96.0	94.3	96.3	96.1	95.5	96.3	95.8
98.9	11	99.6	99.8	99.9	99.4	99.7	99.9	99.4	99.6	99.2	99.8
99.1	12	99.9	100.0	100.0	99.9	99.6	99.7	99.6	99.6	99.7	99.7
	S.I.D.	1.97	1.97	1.96	1.97	1.97	1.93	1.97	1.94	1.93	1.96

*By impression number.

TABLE C-7

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 21° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
4.4	1	0.0	0.0	0.0	0.0	0.0	.2	0.0	0.0	0.0	0.0
14.1	2	6.7	.7	.2	0.0	0.0	5.8	4.8	2.6	.4	.4
24.9	3	14.5	11.7	11.3	11.3	12.5	13.9	11.0	10.4	10.4	10.2
39.4	4	25.7	23.8	25.2	23.1	25.9	23.5	21.8	22.3	22.4	23.2
55.3	5	41.3	43.2	43.9	43.7	43.0	40.6	39.5	39.4	40.3	40.1
71.8	6	52.0	58.2	58.7	57.8	56.5	56.1	59.8	57.2	57.6	58.5
83.6	7	69.2	75.3	75.1	74.2	72.9	75.6	74.7	74.7	76.6	76.0
89.8	8	79.9	85.4	84.9	85.2	83.1	87.0	86.5	85.2	84.5	84.8
94.5	9	88.5	93.7	92.8	90.4	89.2	92.5	92.1	91.1	90.5	91.4
97.4	10	94.4	97.2	97.9	97.6	96.2	97.9	97.0	96.6	97.7	97.9
98.8	11	99.6	100.0	99.7	99.6	99.1	99.6	99.0	98.9	98.5	99.8
99.3	12	100.0	100.0	100.0	99.7	99.5	99.6	99.4	99.6	99.5	99.9
	S.I.D.	1.96	1.97	1.98	1.97	1.95	1.98	1:96	1.94	1.94	1.94

*By impression number.

Appendix C

TABLE C-8

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 22.5° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
3.4	1	0.0	0.0	0.0	.2	0.0	0.0	0.0	0.0	0.0	0.0
14.0	2	8.3	.2	0.0	.7	0.0	4.8	3.4	1.4	.2	0.0
26.0	3	17.3	11.4	10.8	10.6	8.7	12.6	11.5	10.8	11.3	11.0
40.8	4	26.8	22.3	25.6	25.4	23.1	22.4	22.4	21.8	21.9	22.2
56.2	5	43.1	44.5	42.1	42.6	42.0	40.0	40.5	40.9	40.2	40.2
70.7	6	52.8	59.7	60.0	57.4	55.9	56.9	59.3	58.2	59.1	57.9
81.2	7	67.9	72.5	71.7	72.2	70.2	70.1	74.5	73.1	72.7	72.1
88.6	8	77.8	85.2	83.0	82.8	80.8	83.1	83.7	83.8	83.1	83.9
93.1	9	88.5	91.6	90.0	90.6	89.1	89.6	90.0	89.0	90.1	90.4
96.5	10	95.4	96.5	96.1	95.5	94.3	95.9	95.2	96.5	95.2	95.4
98.2	11	98.0	98.9	99.0	98.9	99.5	98.9	99.7	98.9	99.9	99.2
99.3	12	99.9	100.0	100.0	100.0	100.0	99.8	99.9	99.5	100.0	99.7
	S.I.D.	1.98	1.98	1.98	1.98	1.98	1.95	1.96	1.95	1.92	1.98

*By impression number.

TABLE C-9

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 30° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
2.9	1	0.0	0.0	0.0	0.0	0.0	.2	0.0	0.0	0.0	0.0
10.6	2	6.5	0.0	0.0	0.0	0.0	2.9	1.4	.4	.4	0.0
22.1	3	15.0	12.2	12.1	10.6	9.6	10.0	9.2	9.0	6.9	6.7
39.1	4	27.6	27.8	29.3	28.5	29.9	21.1	20.6	21.1	21.3	21.1
56.2	5	43.3	47.1	47.7	48.0	44.4	41.3	40.5	40.8	41.2	40.7
72.1	6	56.1	63.9	62.5	63.1	60.2	57.5	59.2	59.1	61.3	59.3
83.8	7	70.7	77.4	75.9	75.8	72.8	76.8	76.8	76.6	75.7	76.6
90.0	8	81.7	86.8	85.4	85.5	84.3	87.5	86.5	87.3	86.5	85.1
93.9	9	87.4	92.9	90.5	91.2	88.9	91.7	92.1	91.5	91.0	91.1
96.9	10	95.3	96.9	96.0	96.6	94.4	98.4	97.0	97.0	97.4	97.4
98.6	11	98.6	100.0	99.5	99.4	99.3	100.0	99.8	99.6	100.0	100.0
99.1	12	99.8	100.0	100.0	99.9	99.9	100.0	99.9	99.7	100.0	100.0
	S.I.D.	1.96	1.94	1.99	1.97	1.98	1.94	1.96	1.94	1.94	1.93

*By impression number.

Appendix C

TABLE C-10

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 39° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
1.1	1	0.0	0.0	.2	0.0	0.0	.7	0.0	0.0	0.0	0.0
9.6	2	4.6	0.0	.2	.2	0.0	5.3	2.1	0.0	0.0	0.0
20.9	3	14.3	2.9	3.6	4.1	2.1	10.6	8.3	7.0	6.7	5.3
37.0	4	24.9	17.7	18.7	18.3	18.1	21.0	18.9	18.2	18.6	18.6
54.9	5	38.5	41.9	41.2	40.6	38.5	40.0	39.2	40.8	41.0	40.7
75.0	6	57.3	63.8	61.4	61.6	59.2	62.6	60.9	62.7	64.0	63.3
86.4	7	76.8	80.7	79.0	78.5	76.3	78.2	79.8	78.1	78.1	78.3
91.8	8	84.9	89.2	86.9	86.8	85.1	87.9	88.9	89.2	88.5	88.9
97.2	9	95.8	97.2	96.0	96.1	95.5	96.9	97.8	97.5	97.3	96.7
98.4	10	99.5	99.5	99.0	98.9	98.1	99.3	99.6	99.3	99.6	99.6
99.3	11	99.9	100.0	100.0	99.9	99.7	100.0	99.9	100.0	100.0	100.0
99.4	12	99.9	100.0	100.0	99.9	99.9	100.0	100.0	100.0	100.0	100.0
	S.I.D.	1.97	1.97	1.98	1.98	1.99	1.96	1.97	1.93	1.94	1.95

*By impression number.

Appendix C

TABLE C-11

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 45° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
2.7	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.1	2	7.8	0.0	0.0	0.0	.2	6.5	3.4	2.1	.4	.4
23.4	3	13.9	8.1	6.4	4.8	2.6	16.3	12.2	10.4	10.2	9.7
40.1	4	28.5	19.5	21.8	22.8	22.1	23.2	24.2	23.7	24.4	27.4
55.8	5	43.2	46.3	45.1	44.8	41.0	40.1	37.3	38.5	39.1	39.1
70.9	6	55.9	62.4	62.6	59.5	55.3	52.6	54.9	53.2	54.1	55.7
82.4	7	69.7	75.8	76.1	72.7	72.5	69.7	73.6	71.2	71.1	70.6
89.2	8	79.9	85.8	82.2	84.1	82.0	85.9	86.5	86.6	85.7	85.6
93.9	9	89.4	93.1	91.9	92.1	89.0	91.6	92.8	91.2	91.7	92.0
96.9	10	96.6	96.7	96.5	97.4	95.1	97.4	97.7	98.2	97.3	96.5
98.7	11	99.9	99.6	99.5	99.6	98.7	99.6	99.6	99.4	99.7	99.3
99.3	12	100.0	100.0	100.0	100.0	100.0	99.8	99.7	99.7	99.5	99.6
	S.I.D.	1.98	1.99	1.98	1.97	1.99	1.95	1.94	1.92	1.94	1.96

*By impression number.

Appendix C

TABLE C-12

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 51° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
0.0	1	0.0	0.0	.2	0.0	0.0	0.0	.2	0.0	0.0	.2
2.1	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	.2
16.4	3	10.5	.9	0.0	0.0	0.0	5.5	4.3	2.1	1.2	1.2
33.1	4	23.1	17.9	15.4	15.9	17.3	15.4	14.9	14.8	14.1	14.8
52.4	5	34.9	39.0	41.5	39.0	37.5	35.7	35.7	36.4	35.9	35.7
69.4	6	48.2	57.3	56.2	56.5	52.3	52.4	53.0	51.7	53.3	52.7
82.5	7	68.3	76.2	74.8	74.7	71.6	72.9	75.0	75.0	73.9	74.1
90.0	8	80.6	84.9	85.3	86.0	84.2	85.1	85.9	85.3	84.7	84.8
94.0	9	87.8	93.3	91.2	91.9	90.1	92.4	91.5	90.6	90.9	90.2
97.1	10	95.8	97.4	96.8	96.7	95.8	97.3	97.0	97.3	97.3	96.3
98.6	11	98.6	99.7	99.6	99.7	99.9	99.5	99.6	99.7	99.8	100.0
99.2	12	99.6	100.0	100.0	100.0	100.0	99.8	99.6	99.7	99.9	100.0
	S.I.D.	1.98	1.98	1.98	1.95	1.96	1.95	1.94	1.95	1.95	1.96

*By impression number.

Appendix C

TABLE C-13

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 60° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
0.0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.2	2	.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.6	3	12.6	1.7	.4	.2	0.0	10.4	6.7	5.5	4.3	4.1
35.4	4	23.4	18.1	18.3	19.8	20.2	19.8	19.1	19.6	20.2	20.3
53.3	5	38.3	40.2	41.6	42.0	38.1	37.4	37.6	37.1	38.9	38.7
69.2	6	52.9	56.8	59.3	56.9	53.9	52.4	52.6	54.6	54.8	53.2
82.7	7	70.9	75.1	75.0	75.3	72.2	76.2	75.3	75.1	75.5	76.2
89.8	8	79.9	86.3	85.1	83.2	83.3	83.8	85.1	84.3	84.8	85.1
95.3	9	90.7	94.1	91.8	92.4	90.7	92.9	93.5	92.0	93.3	92.8
96.9	10	94.2	95.1	96.0	95.9	93.5	96.3	97.1	95.3	96.0	96.8
99.1	11	99.8	100.0	99.9	99.9	99.6	99.8	99.9	100.0	100.0	100.0
99.3	12	99.7	100.0	99.9	99.9	100.0	99.7	99.6	99.4	99.9	100.0
	S.I.D.	1.98	1.98	1.99	1.97	1.97	1.95	1.98	1.97	1.96	1.94

*By impression number.

Appendix C

TABLE C-14

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 67.5° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
0.0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2
0.0	2	0.0	.2	.2	.2	.2	0.0	0.0	0.0	.2	.2
11.9	3	7.8	0.0	.2	.2	.2	3.1	1.1	.2	0.0	.2
29.1	4	19.4	11.7	11.4	9.9	11.4	14.1	11.6	11.7	11.3	11.1
51.5	5	34.8	36.8	34.5	37.0	35.7	32.8	34.3	34.9	34.8	34.1
70.6	6	52.4	56.6	57.7	56.0	53.1	55.7	56.6	56.0	54.7	53.7
83.7	7	70.4	76.3	73.9	74.0	72.4	73.3	74.1	74.0	74.2	74.6
89.8	8	80.2	86.0	84.1	84.7	81.7	85.7	85.5	84.5	85.0	85.1
94.3	9	88.4	92.3	91.9	91.1	89.5	92.4	90.6	90.9	91.1	91.2
96.8	10	94.7	96.3	97.0	95.2	95.4	96.7	96.5	96.0	95.8	97.2
98.3	11	98.7	99.3	98.7	98.8	98.5	99.4	98.7	99.7	99.4	99.2
99.1	12	99.7	99.9	99.5	100.0	100.0	99.8	98.8	99.8	99.5	99.7
	S.I.D.	1.97	1.97	1.99	1.97	1.98	1.95	1.96	1.94	1.98	1.95

*By impression number.

Appendix C

TABLE C-15

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 69° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
3.2	1	.7	0.0	0.0	0.0	0.0	.2	.2	.2	0.0	0.0
11.7	2	7.2	0.0	0.0	0.0	0.0	7.6	4.1	2.6	1.2	.2
22.1	3	16.4	7.1	6.7	5.1	5.3	13.9	11.9	11.3	11.7	11.8
35.3	4	26.4	21.3	21.8	23.4	25.0	24.4	23.8	23.4	24.6	27.0
52.0	5	37.6	38.5	39.8	39.9	39.9	37.5	38.5	37.9	38.0	37.8
67.9	6	47.6	53.4	55.3	54.9	51.4	51.6	53.7	52.1	54.2	53.6
80.8	7	67.4	71.8	72.9	72.4	69.0	72.2	72.9	72.5	72.6	73.1
88.0	8	76.9	82.0	81.6	82.2	79.4	82.1	82.9	82.4	82.2	82.3
92.9	9	85.8	89.3	89.1	88.5	85.9	90.7	90.9	90.7	89.5	90.8
96.2	10	92.7	94.5	95.7	94.7	93.2	95.5	97.0	96.5	95.9	96.6
98.3	11	98.5	97.5	99.2	99.4	98.2	99.6	100.0	99.6	99.5	99.7
99.3	12	99.7	99.0	100.0	100.0	99.8	99.9	99.6	99.6	100.0	100.0
	S.I.D.	1.97	2.00	1.97	1.96	1.98	1.94	1.96	1.94	1.96	1.92

*By impression number.

Appendix C

TABLE C-16

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 72° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2 *				
		2	16	22	25	40	7	14	23	32	38
.3	1	.4	0.0	0.0	0.0	0.0	0.0	.2	0.0	0.0	0.0
8.9	2	1.7	0.0	0.0	.2	.2	3.1	2.6	1.0	.2	0.0
20.5	3	13.5	7.4	4.1	3.9	1.4	16.1	10.6	8.8	8.6	8.6
34.5	4	24.5	23.3	22.9	23.5	22.8	21.6	18.4	19.7	19.9	20.5
53.8	5	38.0	44.5	48.7	47.4	43.0	35.2	35.8	35.9	35.4	34.8
70.7	6	55.3	61.9	63.0	61.7	58.4	54.5	56.2	56.1	56.4	55.5
83.2	7	73.6	77.2	79.2	77.2	75.0	71.8	74.6	73.2	75.1	74.3
90.4	8	83.6	88.3	86.7	86.6	88.1	85.8	86.4	86.0	84.7	87.5
94.3	9	91.1	94.5	93.6	94.2	93.3	92.9	94.1	93.9	93.5	93.5
97.1	10	98.1	98.4	97.8	97.9	97.7	98.9	98.9	97.7	98.2	98.6
98.5	11	99.5	99.6	99.9	99.6	99.7	99.4	99.7	100.0	100.0	100.0
99.3	12	100.0	100.0	100.0	99.8	100.0	99.7	99.6	100.0	100.0	100.0
	S.I.D.	1.98	2.00	1.99	2.00	1.97	1.95	1.95	1.92	1.93	1.93

*By impression number.

TABLE C-17

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 75° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
0.0	1	.2	0.0	0.0	0.0	0.0	0.0	0.0	.4	.4	0.0
5.9	2	.2	0.0	0.0	0.0	0.0	.4	0.0	.2	0.0	0.0
18.1	3	13.0	5.5	2.4	1.7	.9	6.7	5.8	4.1	1.2	1.2
34.7	4	26.7	23.7	23.1	25.5	23.8	18.8	18.0	18.3	17.5	17.2
55.0	5	39.4	43.5	42.1	43.4	40.9	38.8	39.0	38.8	38.6	38.3
71.2	6	55.8	60.5	58.3	59.0	56.3	57.0	56.7	55.9	55.7	56.1
84.0	7	71.1	77.7	75.0	76.5	75.2	75.8	77.3	75.5	75.8	75.2
90.7	8	80.4	89.2	87.4	85.6	85.7	84.0	85.9	84.7	85.3	83.7
94.4	9	88.4	94.9	92.1	93.2	92.5	91.3	92.4	91.1	91.4	91.5
98.6	10	96.9	98.7	99.2	98.8	99.2	98.4	99.9	99.3	99.5	99.7
99.4	11	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
99.3	12	99.2	100.0	100.0	100.0	100.0	99.5	100.0	99.4	100.0	100.0
	S.I.D.	2.00	1.97	1.99	1.97	1.97	1.94	1.94	1.98	1.96	1.94

*By impression number.

Appendix C

TABLE C-18

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 81° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
.1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.6	2	.4	0.0	0.0	0.0	0.0	0.0	.2	0.0	0.0	0.0
16.9	3	13.2	2.9	1.9	1.2	.4	13.5	7.4	8.8	7.9	7.6
34.0	4	24.3	21.3	21.1	19.8	20.8	21.3	19.7	20.5	19.2	18.6
54.1	5	39.9	45.8	46.1	43.1	44.0	37.6	37.5	38.5	38.5	39.1
70.6	6	56.6	61.8	59.8	61.7	57.5	55.9	56.3	54.3	55.4	54.9
83.5	7	72.4	77.7	75.3	76.6	75.9	73.3	77.4	73.2	73.9	75.9
90.3	8	83.3	86.4	85.8	86.1	83.2	85.7	85.7	84.7	85.7	84.6
94.1	9	89.2	92.2	92.6	93.1	91.8	91.1	92.3	90.5	92.5	91.6
97.0	10	95.4	97.3	96.9	96.8	96.4	95.9	97.8	96.3	96.8	97.4
98.8	11	98.8	99.6	99.6	99.2	99.5	99.5	100.0	100.0	99.7	100.0
99.2	12	99.6	99.7	99.9	99.9	100.0	99.2	99.9	99.3	99.5	100.0
	S.I.D.	1.97	2.01	1.99	1.96	1.97	1.95	1.93	1.93	1.95	1.94

*By impression number.

TABLE C-19

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 84° ANGLE

Positive Film Dot Area	Step	Run 1*					Run 2*				
		2	16	22	25	40	7	14	23	32	38
0.0	1	0.0	0.0	0.0	0.0	.2	0.0	.2	0.0	.2	0.0
0.0	2	.2	.2	.2	0.0	.2	0.0	0.0	.2	.4	.2
4.9	3	.2	0.0	0.0	0.0	.2	.2	0.0	0.0	.2	.2
26.0	4	18.9	12.4	12.8	13.2	14.7	13.3	10.6	9.7	9.7	9.6
49.4	5	34.4	35.9	37.5	35.8	35.6	32.4	33.7	33.7	33.7	33.9
70.2	6	50.4	55.4	56.5	55.7	52.3	54.5	55.6	55.6	53.8	54.6
85.2	7	74.7	77.9	76.6	76.2	74.6	78.0	79.1	77.7	78.1	77.3
91.1	8	82.9	87.9	87.4	87.3	83.9	88.0	87.7	87.1	86.8	86.3
95.1	9	90.6	93.4	93.1	93.1	90.9	93.5	93.8	92.7	93.5	91.3
97.3	10	95.8	97.6	96.4	96.8	97.1	97.8	97.9	98.2	98.1	97.1
98.8	11	99.5	99.2	99.6	99.6	99.6	99.9	100.0	99.8	99.8	99.4
99.2	12	99.6	100.0	100.0	99.9	100.0	99.9	100.0	99.9	99.1	99.3
	S.I.D.	1.98	1.98	1.98	1.98	1.97	1.95	1.95	1.94	1.94	2.02

*By impression number.

Appendix C

TABLE C-20

MEDIAN PERCENT DOT AREAS FOR EXPERIMENTAL SAMPLES AT 90° ANGLE

Positive Film		Run 1*					Run 2*				
Dot Area	Step	2	16	22	25	40	7	14	23	32	38
0.0	1	0.0	0.0	0.0	.2	0.0	0.0	0.0	0.0	0.0	0.0
0.0	2	0.0	0.0	0.0	.2	0.0	0.0	0.0	0.0	0.0	0.0
6.7	3	.7	0.0	0.0	.2	0.0	.4	0.0	0.0	0.0	0.0
27.1	4	22.5	17.3	14.7	15.2	15.2	13.9	11.7	10.6	10.6	11.3
49.4	5	34.7	37.7	40.0	38.3	35.9	31.4	31.8	32.3	33.1	33.3
69.8	6	52.1	56.0	57.9	57.1	54.6	53.6	52.8	54.4	53.0	53.8
84.3	7	71.2	76.0	77.0	75.8	74.8	75.2	78.1	76.6	77.0	77.0
91.0	8	81.3	84.4	84.4	86.0	85.3	86.7	86.9	86.5	87.3	86.4
95.1	9	88.6	93.0	91.8	91.6	89.9	92.7	92.2	92.6	94.0	93.4
97.9	10	94.9	98.7	97.3	96.5	97.1	98.2	98.6	98.7	98.8	98.3
98.9	11	98.5	99.7	100.0	100.0	99.5	100.0	100.0	99.5	99.8	100.0
99.3	12	99.8	100.0	100.0	100.0	99.7	100.0	99.8	99.6	100.0	100.0
	S.I.D.	1.98	1.99	1.98	1.97	1.99	1.94	1.96	1.94	1.94	1.94

*By impression number.

Appendix C

TABLE C-21

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 0° ANGLE

Gray Scale	Run 1*						Run 2*						
Step	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
2	-3.2	-12.9	-13.1	-13.1	-12.9	-55.2	-7.1	-9.7	-10.0	-13.1	-13.1	-53.0	-10.82
3	-10.1	-13.5	-13.3	-14.8	-15.5	-67.2	-11.9	-15.0	-15.9	-14.8	-14.7	-72.3	-13.95
4	-11.7	-13.3	-12.2	-14.6	-12.6	-64.4	-19.4	-16.8	-16.4	-18.8	-18.6	-90.0	-15.44
5	-7.3	-7.1	-7.9	-7.3	-11.7	-41.3	-16.2	-12.1	-14.4	-11.3	-12.7	-66.7	-10.80
6	-12.9	-5.6	-7.1	-7.5	-14.0	-47.1	-14.6	-11.3	-13.0	-11.5	-12.6	-63.0	-11.01
7	-9.2	-3.9	-5.8	-4.4	-7.2	-30.5	-4.7	-5.0	-8.0	-8.1	-8.3	-34.1	-6.46
8	-5.8	-1.6	-2.9	-4.1	-6.4	-20.8	-6.8	-5.2	-6.6	-7.2	-6.1	-31.9	-5.27
9	-4.9	-0.5	-1.5	-1.8	-3.7	-12.4	-3.2	-3.6	-3.3	-3.0	-3.1	-16.2	-2.86
10	-1.5	+0.5	+0.9	+0.5	-0.1	+0.3	-2.3	-1.0	-1.9	-1.0	-1.2	-7.4	-0.71
11	+0.6	+0.9	+0.8	+0.1	+0.9	+3.3	+1.0	+0.6	+1.1	+1.0	+1.0	+4.7	+0.80

*By impression number

TABLE C-22

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 6° ANGLE

Gray Scale Step	Run 1*						Run 2*						$\bar{x}$
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	
2	-5.5	-7.9	-7.9	-7.9	-7.9	-37.1	-4.5	-7.2	-7.9	-7.9	-7.7	-35.2	-7.23
3	-5.7	-14.4	-15.5	-15.7	-17.1	-68.4	-8.0	-11.6	-12.7	-13.2	-12.3	-57.8	-12.62
4	-9.2	-12.4	-11.5	-10.9	-10.7	-54.7	-15.9	-16.8	-15.8	-15.4	-15.8	-79.7	-13.44
5	-8.2	+0.1	-2.4	-1.2	-7.9	-18.4	-14.3	-12.2	-12.6	-13.1	-11.1	-63.3	-8.17
6	-16.6	-7.5	-9.3	-10.5	-11.0	-54.9	-12.8	-10.1	-10.6	-12.4	-11.9	-57.8	-11.27
7	-12.3	-5.2	-6.8	-6.8	-8.7	-39.8	-7.6	-6.7	-7.5	-7.5	-7.5	-36.8	-7.66
8	-9.2	-3.1	-4.2	-4.4	-5.8	-26.7	-4.8	-3.9	-5.5	-5.3	-5.2	-24.7	-5.14
9	-5.2	-1.8	-2.4	-2.9	-5.3	-17.6	-3.0	-2.9	-2.9	-3.8	-2.9	-15.5	-3.31
10	-0.4	±0.0	+0.3	-0.8	-0.5	-1.4	+0.5	+0.2	+0.4	+0.3	+0.3	+1.7	+0.30
11	+0.7	+0.6	+0.8	-0.4	+1.0	+2.7	+1.3	+1.0	+1.0	+0.2	+1.5	+5.0	+0.77

*By impression number.

TABLE C-23

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 9° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
3	-4.7	-13.2	-13.4	-15.3	-16.3	-62.9	-9.4	-10.8	-12.0	-14.5	-14.1	-60.8	-12.37
4	-9.1	-12.1	-11.8	-8.8	-9.2	-51.0	-17.2	-17.7	-18.2	-18.3	-16.9	-88.3	-13.93
5	-11.7	-8.2	-5.9	-8.0	-10.7	-44.5	-15.1	-16.8	-15.7	-14.5	-15.2	-77.3	-12.18
6	-15.8	-11.2	-11.3	-13.3	-15.9	-67.5	-10.6	-12.0	-11.6	-10.9	-13.4	-58.5	-12.60
7	-11.6	-6.3	-8.8	-9.5	-11.2	-47.4	-8.9	-8.4	-8.5	-7.7	-9.5	-43.0	-9.04
8	-8.9	-3.0	-4.3	-5.4	-7.2	-28.8	-3.8	-3.0	-4.9	-3.9	-4.6	-20.2	-4.90
9	-5.9	-1.1	-2.0	-2.6	-4.7	-16.3	-2.2	-1.9	-2.1	-2.0	-2.7	-10.9	-2.72
10	-0.5	+0.1	±0.0	+0.2	-0.8	-1.0	+0.3	+1.1	+0.8	+0.5	+0.7	+3.4	+0.24
11	+0.7	+0.8	+1.1	+0.9	+0.7	+4.2	+1.1	+1.1	+1.1	+1.1	+1.1	+5.5	+0.97

*By impression number.

TABLE C-24

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 15° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
2	-4.2	-12.8	-13.0	-13.0	-13.0	-56.0	-1.3	-7.0	-8.4	-9.6	-10.6	-36.9	-9.29
3	-6.2	-11.7	-10.2	-11.7	-13.0	-52.8	-7.2	-9.6	-10.4	-7.9	-9.5	-44.6	-9.74
4	-10.1	-8.9	-7.5	-4.9	-9.8	-41.2	-12.1	-14.1	-13.1	-12.7	-12.1	-64.1	-10.53
5	-8.6	-1.1	-0.8	-2.6	-6.6	-19.7	-11.1	-13.0	-12.4	-11.1	-11.9	-59.5	-7.92
6	-14.3	-4.5	-4.9	-5.3	-11.2	-40.2	-11.9	-11.8	-12.1	-11.9	-12.0	-59.7	-9.99
7	-11.6	-5.0	-6.0	-5.9	-9.0	-37.5	-8.3	-7.2	-8.5	-8.4	-8.5	-40.9	-7.84
8	-8.8	-3.2	-3.5	-4.5	-6.5	-26.5	-5.1	-5.8	-6.2	-6.8	-5.7	-29.6	-5.61
9	-5.9	-1.8	-2.1	-2.5	-4.3	-16.6	-2.8	-2.0	-2.5	-1.6	-2.1	-11.0	-2.76
10	-2.4	-0.1	-0.6	-0.2	-0.9	-4.2	-1.0	+0.2	-0.4	-0.8	±0.0	-2.0	-0.62
11	+0.2	+1.0	+0.7	+0.6	+0.4	+2.9	+1.3	+1.6	+0.9	+1.1	+1.8	+6.7	+0.96

*By impression number.

Appendix C

TABLE C-25

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 18° ANGLE

Gray Scale Step	Run 1*						Run 2*						$\bar{x}$
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	
2	-6.2	-13.6	-13.3	-13.6	-14.5	-61.2	-9.0	-10.4	-12.1	-14.1	-14.5	-60.1	-12.13
3	-7.1	-11.4	-11.7	-9.5	-11.2	-50.9	-13.5	-14.7	-15.3	-14.4	-13.9	-71.8	-12.27
4	-12.5	-16.3	-13.9	-12.2	-11.7	-66.6	-17.3	-17.7	-17.8	-18.4	-19.0	-90.2	-15.68
5	-15.1	-8.0	-10.0	-10.1	-12.3	-55.5	-15.5	-15.5	-16.0	-15.0	-14.3	-76.3	-13.18
6	-18.5	-10.5	-9.7	-12.2	-14.0	-64.9	-14.6	-13.1	-12.8	-12.7	-12.6	-65.8	-13.07
7	-13.8	-8.1	-7.0	-8.6	-10.2	-47.7	-8.7	-8.1	-9.8	-8.3	-8.7	-43.6	-9.13
8	-10.5	-6.2	-6.3	-7.1	-6.8	-36.9	-4.4	- 6.4	-6.4	-6.0	-5.3	-28.5	-6.54
9	-8.5	-2.5	-3.2	-3.6	-6.0	-23.8	-2.2	-3.1	-4.3	-3.0	-3.1	-15.7	-3.95
10	-4.0	+0.2	-0.6	-0.2	-1.9	-6.5	+0.1	-0.1	-0.7	+0.1	-0.4	-1.0	-0.75
11	+0.7	+0.9	+1.0	+0.5	+0.8	+3.9	+1.0	+0.5	+0.7	+0.3	+0.9	+3.4	+0.73

*By impression number.

TABLE C-26

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 21° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
2	-7.4	-13.4	-13.9	-14.1	-14.1	-62.9	-8.3	-9.3	-11.5	-13.7	-13.7	-56.5	-11.94
3	-10.4	-13.2	-13.6	-13.6	-12.4	-63.2	-11.0	-13.9	-14.5	-14.5	-14.7	-68.6	-13.18
4	-13.7	-15.6	-14.2	-16.3	-13.5	-73.3	-15.9	-17.6	-17.1	-17.0	-16.2	-83.8	-15.71
5	-14.0	-12.1	-11.4	-11.6	-12.3	-61.4	-14.7	-15.8	-15.9	-15.0	-15.2	-76.6	-13.80
6	-19.8	-13.6	-13.1	-14.0	-15.3	-75.8	-15.7	-12.0	-14.6	-14.2	-13.3	-69.8	-14.56
7	-14.4	-8.3	-8.5	-9.4	-10.7	-51.3	-8.0	-8.9	-8.9	-7.0	-7.6	-40.4	-9.17
8	-9.9	-4.4	-4.9	-4.6	-6.7	-30.5	-2.8	-3.3	-4.6	-5.3	-5.0	-21.0	-5.15
9	-6.0	-0.8	-1.7	-4.1	-5.3	-17.9	-2.0	-2.4	-3.4	-4.0	-3.1	-14.9	-3.28
10	-3.0	-0.2	+0.5	+0.2	-1.2	-3.7	+0.5	-0.4	-0.8	+0.3	+0.5	+0.1	-0.36
11	+0.8	+1.2	+0.9	+0.8	+0.3	+4.0	+0.8	+0.2	+0.1	-0.3	+1.0	+1.8	+0.58

*By impression number.

Appendix C

TABLE C-27

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 22.5° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
2	-5.7	-13.8	-14.0	-13.3	-14.0	-60.8	-9.2	-10.6	-12.6	-13.8	-14.0	-60.2	-12.10
3	-8.7	-14.6	-15.2	-15.4	-17.3	-71.2	-13.4	-14.5	-15.2	-14.7	-15.0	-72.8	-14.40
4	-14.0	-18.5	-15.2	-15.4	-17.7	-80.8	-18.4	-18.4	-19.0	-18.9	-18.6	-93.3	-17.41
5	-13.1	-11.7	-14.1	-13.6	-14.2	-66.7	-16.2	-15.7	-15.3	-16.0	-16.0	-79.2	-14.59
6	-17.9	-11.0	-10.7	-13.3	-14.8	-67.7	-13.8	-11.4	-12.5	-11.6	-12.8	-62.1	-12.98
7	-13.3	-8.7	-9.5	-9.0	-11.0	-51.5	-11.1	-6.7	-8.1	-8.5	-9.1	-43.5	-9.50
8	-10.8	-3.4	-5.6	-5.8	-7.8	-33.4	-5.5	-4.9	-4.8	-5.5	-4.7	-25.4	-5.88
9	-4.6	-1.5	-3.1	-2.5	-4.0	-15.7	-3.5	-3.1	-4.1	-3.0	-2.7	-16.4	-3.21
10	-1.1	±0.0	-0.4	-1.0	-2.2	-4.7	-0.6	-1.3	±0.0	-1.3	-1.1	-4.3	-0.90
11	-0.2	+0.7	+0.8	+0.7	+1.3	+3.3	+0.7	+1.5	+0.7	+1.7	+1.0	+5.6	+0.89

*By impression number.

TABLE C-28

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 30° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
2	-4.1	-10.6	-10.6	-10.6	-10.6	-46.5	-7.7	-9.2	-10.2	-10.2	-10.6	-47.9	-9.44
3	-7.1	-9.9	-10.0	-11.5	-12.5	-51.0	-12.1	-12.9	-13.1	-15.2	-15.4	-68.7	-11.97
4	-11.5	-11.3	-9.8	-10.6	-9.2	-52.4	-18.0	-18.5	-18.0	-17.8	-18.0	-90.3	-14.27
5	-12.9	-9.1	-8.5	-8.2	-11.8	-50.5	-14.9	-15.7	-15.4	-15.0	-15.5	-76.5	-12.70
6	-16.0	-8.2	-9.6	-9.0	-11.9	-54.7	-14.6	-12.9	-13.0	-10.8	-12.8	-64.1	-11.88
7	-13.1	-6.4	-7.9	-8.0	-11.0	-46.4	-7.0	-7.0	-7.2	-8.1	-7.2	-36.5	-8.29
8	-8.3	-3.2	-4.6	-4.5	-5.7	-26.3	-2.5	-3.5	-2.7	-3.5	-4.9	-17.1	-4.34
9	-6.5	-1.0	-3.4	-2.7	-5.0	-18.6	-2.2	-1.8	-2.4	-2.9	-2.8	-12.1	-3.07
10	-1.6	±0.0	-0.9	-0.3	-2.5	-5.3	+1.5	+0.1	+0.1	+0.5	+0.5	+2.7	-0.26
11	±0.0	+1.4	+0.9	+0.8	+0.7	+3.8	+1.4	+1.2	+1.0	+1.4	+1.4	+6.4	+1.02

*By impression number.

TABLE C-29

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 39° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
2	-5.0	-9.6	-9.4	-9.4	-9.6	-43.0	-4.3	-7.5	-9.6	-9.6	-9.6	-40.6	-8.36
3	-6.6	-18.0	-17.3	-16.8	-18.8	-77.5	-10.3	-12.6	-13.9	-14.2	-15.6	-66.6	-14.41
4	-12.1	-19.3	-18.3	-18.7	-18.9	-87.3	-16.0	-18.1	-18.8	-18.4	-18.4	-89.7	-17.70
5	-16.4	-13.0	-13.7	-14.3	-16.4	-73.8	-14.9	-15.7	-14.1	-13.9	-14.2	-72.8	-14.66
6	-17.7	-11.2	-13.6	-13.4	-15.8	-71.7	-12.4	-14.1	-12.3	-11.0	-11.7	-61.5	-13.32
7	-9.6	-5.7	-7.4	-7.9	-10.1	-30.6	-8.2	-6.6	-8.3	-8.3	-8.1	-39.5	-7.01
8	-6.9	-2.6	-4.9	-5.0	-6.7	-26.1	-3.9	-2.9	-2.6	-3.3	-2.9	-15.6	-4.17
9	-1.4	±0.0	-1.2	-1.1	-1.7	-5.4	-0.3	+0.6	+0.3	+0.1	-0.5	+0.2	-0.52
10	+1.5	+1.6	+1.6	+1.5	+1.3	+7.5	+1.6	+1.5	+1.6	+1.6	+1.6	+7.9	+1.54

*By impression number.

TABLE C-30

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 45° ANGLE

Gray Scale Step	Run 1* 2	Run 1* 16	Run 1* 22	Run 1* 25	Run 1* 40	Run 1* Sum	Run 2* 7	Run 2* 14	Run 2* 23	Run 2* 32	Run 2* 38	Run 2* Sum	$\bar{x}$
2	-3.3	-11.1	-11.1	-11.1	-11.1	-47.7	-4.6	-7.7	-9.0	-10.7	-10.7	-42.7	-9.04
3	-9.5	-15.3	-17.0	-18.6	-20.8	-81.2	-7.1	-11.2	-13.0	-13.2	-13.7	-58.2	-13.94
4	-11.6	-20.6	-18.3	-17.3	-18.0	-85.8	-16.9	-15.9	-16.4	-15.7	-12.7	-77.6	-16.34
5	-12.6	-9.5	-10.7	-11.0	-14.8	-58.6	-15.7	-18.3	-17.3	-16.7	-16.7	-84.7	-14.33
6	-15.0	-8.5	-8.3	-11.4	-15.6	-58.8	-18.3	-16.0	-17.7	-16.8	-15.2	-84.0	-14.25
7	-12.7	-6.6	-6.3	-9.7	-9.9	-45.2	-12.7	-8.8	-11.2	-11.3	-11.8	-55.8	-10.10
8	-9.3	-3.4	-7.0	-5.1	-7.2	-32.0	-3.3	-2.7	-2.6	-3.5	-3.6	-15.7	-4.72
9	-4.5	-0.8	-2.0	-1.8	-4.9	-14.0	-2.3	-1.1	-2.7	-2.2	-1.9	-10.2	-2.42
10	-0.3	-0.2	-0.4	+0.5	-1.8	-2.2	+0.5	+0.8	+1.3	+0.4	-0.4	+2.6	+0.40
11	+1.2	+0.9	+0.8	+0.9	±0.0	+3.8	+0.9	+0.9	+0.7	+1.0	+0.6	+4.1	+0.79

*By impression number.

TABLE C-31

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 51° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
3	-5.9	-15.5	-16.4	-16.4	-16.4	-70.6	-10.9	-12.1	-14.3	-15.2	-15.2	-67.7	-13.83
4	-10.0	-15.2	-17.7	-17.2	-15.8	-75.9	-17.7	-18.2	-18.3	-19.0	-18.3	-91.5	-16.74
5	-17.5	-13.4	-10.9	-13.4	-14.9	-70.1	-16.7	-16.7	-16.0	-16.5	-16.7	-82.6	-15.27
6	-21.2	-12.1	-13.2	-12.9	-17.1	-76.5	-17.0	-16.4	-17.7	-16.1	-16.7	-83.9	-16.04
7	-14.2	-6.3	-7.7	-7.8	-10.9	-46.9	-9.6	-7.5	-7.5	-8.6	-8.4	-41.6	-8.85
8	-9.4	-5.1	-4.7	-4.0	-5.8	-29.0	-4.9	-4.1	-4.7	-5.3	-5.2	-24.2	-5.32
9	-6.2	-0.7	-2.8	-2.1	-3.9	-15.7	-1.6	-2.5	-3.4	-3.1	-3.8	-14.4	-3.01
10	-1.3	+0.3	-0.3	-0.4	-1.3	-3.0	+0.2	-0.1	+0.2	+0.2	-0.8	-0.3	-0.33
11	±0.0	+1.1	+1.0	+1.1	+1.3	+4.5	+0.9	+1.0	+1.1	+1.2	+1.4	+5.6	+1.01

*By impression number.

TABLE C-32

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 60° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
3	-3.0	-13.9	-15.2	-15.4	-15.6	-63.1	-5.2	-8.9	-10.1	-11.3	-11.5	-47.0	-11.01
4	-12.0	-17.3	-17.1	-15.6	-15.2	-77.2	-15.6	-16.3	-15.8	-15.2	-15.1	-78.0	-15.52
5	-15.0	-13.1	-11.7	-11.3	-15.2	-66.3	-15.9	-15.7	-16.2	-14.4	-14.6	-76.8	-14.31
6	-16.3	-12.4	-9.9	-12.3	-15.3	-66.2	-16.8	-16.6	-14.6	-14.4	-16.0	-78.4	-14.46
7	-11.8	-7.6	-7.7	-7.4	-10.5	-45.0	-6.5	-7.4	-7.6	-7.2	-6.5	-35.2	-8.02
8	-9.9	-3.5	-4.7	-6.6	-6.5	-31.2	-6.0	-4.7	-5.5	-5.0	-4.7	-25.9	-5.71
9	-4.6	-1.2	-3.5	-2.9	-4.6	-16.8	-2.4	-1.8	-3.3	-2.0	-2.5	-12.0	-2.88
10	-2.7	-1.8	-0.9	-1.0	-3.4	-9.8	-0.6	+0.2	-1.6	-0.9	-0.1	-3.0	-1.28
11	+0.7	+0.9	+0.8	+0.8	+0.5	+3.7	+0.7	+0.8	+0.9	+0.9	+0.9	+4.2	+0.79

*By impression number.

TABLE C-33

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 67.5° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
3	-4.1	-11.9	-11.7	-11.7	-11.7	-51.1	-8.8	-10.8	-11.7	-11.9	-11.7	-54.9	-10.60
4	-9.7	-17.4	-17.7	-19.2	-17.7	-81.7	-15.0	-17.5	-17.4	-17.8	-18.0	-85.7	-16.74
5	-16.7	-14.7	-17.0	-14.5	-15.8	-78.7	-18.7	-17.2	-16.6	-16.7	-17.4	-86.6	-16.53
6	-18.2	-14.0	-12.9	-14.6	-17.5	-77.2	-14.9	-14.0	-14.6	-15.9	-16.9	-76.3	-15.35
7	-13.3	-7.4	-9.8	-9.7	-11.3	-51.5	-10.4	-9.6	-9.7	-9.5	-9.1	-48.3	-9.98
8	-9.6	-3.8	-5.7	-5.1	-8.1	-32.3	-4.1	-4.3	-5.3	-4.8	-4.7	-23.2	-5.55
9	-5.9	-2.0	-2.4	-3.2	-4.8	-18.3	-1.9	-3.7	-3.4	-3.2	-3.1	-15.3	-3.36
10	-2.1	-0.5	+0.2	-1.6	-1.4	-5.4	-0.1	-0.3	-0.8	-1.0	+0.4	-1.8	-0.72
11	+0.4	+1.0	+0.4	+0.5	+0.2	+2.5	+1.1	+0.4	+1.4	+1.1	+0.9	+4.9	+0.74

*By impression number.

TABLE C-34

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 69° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
2	-4.5	-11.7	-11.7	-11.7	-11.7	-51.3	-4.1	-7.6	-9.1	-10.5	-11.5	-42.8	-9.41
3	-5.8	-15.0	-15.4	-17.0	-16.8	-70.0	-8.2	-10.2	-10.8	-10.4	-10.3	-49.9	-11.99
4	-8.9	-14.0	-13.5	-11.9	-10.3	-58.6	-10.9	-11.5	-11.9	-10.7	-8.3	-53.3	-11.19
5	-14.4	-13.5	-12.2	-12.1	-12.1	-64.3	-14.5	-13.5	-14.1	-14.0	-14.2	-70.3	-13.46
6	-20.3	-14.5	-12.6	-13.0	-16.5	-76.9	-16.3	-14.2	-15.8	-13.7	-14.3	-74.3	-15.12
7	-13.4	-9.0	-7.9	-8.4	-11.8	-50.5	-8.6	-7.9	-8.3	-8.2	-7.7	-40.7	-9.12
8	-11.1	-6.0	-6.4	-5.8	-8.6	-37.9	-5.9	-5.1	-5.6	-5.8	-5.7	-28.1	-6.60
9	-7.1	-3.6	-3.8	-4.4	-7.0	-18.9	-2.2	-2.0	-2.2	-3.4	-2.1	-11.9	-3.08
10	-3.5	-1.7	-0.5	-1.5	-3.0	-10.2	-0.7	+0.8	+0.3	-0.3	+0.4	+0.5	-0.97
11	+0.2	-0.8	+0.9	+1.1	-0.1	+1.3	+1.3	+1.7	+1.3	+1.2	+1.4	+6.9	+0.82

*By impression number.

TABLE C-35

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 72° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
2	-7.2	-8.9	-8.9	-8.7	-8.7	-42.4	-5.8	-6.3	-7.9	-8.7	-8.9	-37.6	-8.00
3	-7.0	-13.1	-16.4	-16.6	-19.1	-72.2	-4.4	-9.9	-11.7	-11.9	-11.9	-49.8	-12.20
4	-10.0	-11.2	-11.6	-11.0	-11.7	-55.5	-12.9	-16.1	-14.8	-14.6	-14.0	-72.4	-12.94
5	-15.8	-9.3	-5.1	-6.4	-10.8	-47.4	-18.6	-18.0	-17.9	-18.4	-19.0	-91.9	-13.93
6	-15.4	-8.8	-7.7	-9.0	-12.3	-53.2	-16.2	-14.5	-14.6	-14.3	-15.2	-74.8	-12.80
7	-9.6	-6.0	-4.0	-6.0	-8.2	-33.8	-11.4	-8.6	-10.0	-8.1	-8.9	-47.0	-8.08
8	-6.8	-2.1	-3.7	-3.8	-2.3	-18.7	-4.6	-4.0	-4.4	-5.7	-2.9	-21.6	-4.03
9	-3.2	+0.2	-0.7	-0.1	-1.0	-4.8	-1.4	-0.2	-0.4	-0.8	-0.8	-3.6	-0.84
10	+1.0	+1.3	+0.7	+0.8	+0.6	+4.4	+1.8	+1.8	+0.6	+1.1	+1.5	+6.8	+1.12
11	+1.0	+1.1	+1.4	+1.1	+1.2	+5.8	+0.9	+1.2	+1.5	+1.5	+1.5	+6.6	+1.24

*By impression number.

TABLE C-36

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 75° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
3	-5.1	-12.6	-15.7	-16.4	-17.2	-67.0	-11.4	-12.3	-14.0	-16.2	-16.2	-71.5	-13.85
4	-8.0	-11.0	-11.6	-9.2	-10.9	-50.7	-15.9	-16.7	-16.4	-17.2	-17.5	-83.7	-13.44
5	-15.6	-11.5	-12.9	-11.6	-14.1	-65.7	-16.2	-16.0	-16.2	-16.4	-16.7	-81.5	-14.72
6	-15.4	-10.7	-12.9	-12.2	-14.9	-66.1	-14.2	-14.5	-15.3	-15.5	-15.1	-74.6	-14.07
7	-12.9	-6.3	-9.0	-7.5	-8.8	-44.5	-8.2	-6.7	-8.5	-8.2	-8.8	-40.4	-8.49
8	-10.3	-1.5	-3.3	-5.1	-5.0	-25.2	-6.7	-4.8	-6.0	-5.4	-7.0	-29.9	-5.51
9	-6.0	+0.5	-2.3	-1.2	-1.9	-10.9	-3.1	-2.0	-3.3	-3.0	-2.9	-11.3	-2.22
10	+0.3	+0.1	+0.6	+0.2	+0.6	+1.8	-0.2	+1.3	+0.7	+0.9	+1.1	+2.9	+0.47

*By impression number.

Appendix C

TABLE C-37

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 81° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
3	-3.7	-14.0	-15.0	-15.7	-16.5	-64.9	-3.4	-9.5	-8.1	-9.0	-9.3	-39.3	-10.42
4	-9.7	-12.7	-12.9	-14.2	-13.2	-62.7	-12.7	-14.3	-13.5	-14.8	-15.4	-70.7	-13.34
5	-14.2	-8.3	-8.0	-11.0	-10.1	-51.6	-16.5	-16.6	-15.6	-15.6	-15.0	-79.3	-13.09
6	-14.0	-8.8	-10.8	-8.9	-13.0	-55.5	-14.7	-14.3	-16.3	-15.2	-15.7	-76.2	-13.17
7	-11.1	-5.8	-8.2	-6.9	-7.6	-39.6	-10.2	-6.1	-10.3	-9.6	-7.6	-43.8	-8.34
8	-7.0	-3.9	-4.5	-4.2	-7.1	-26.7	-4.6	-4.6	-5.6	-4.6	-5.7	-25.1	-5.18
9	-4.9	-1.9	-1.5	-1.0	-2.3	-11.6	-3.0	-1.8	-3.6	-1.6	-2.5	-12.5	-2.41
10	-1.6	+0.3	-0.1	-0.2	-0.6	-2.2	-1.1	+0.8	-0.7	-0.2	+0.4	-0.8	-0.30
11	±0.0	+0.8	+0.8	+0.4	+0.7	+2.7	+0.7	+1.2	+1.2	+0.9	+1.2	+5.2	+0.79

*By impression number.

TABLE C-38

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 84° ANGLE

Gray Scale Step	Run 1*						Run 2*						
	2	16	22	25	40	Sum	7	14	23	32	38	Sum	$\bar{x}$
4	-7.1	-13.6	-13.2	-12.8	-11.3	-58.0	-12.7	-15.4	-16.3	-16.3	-16.4	-77.1	-13.51
5	-15.0	-13.5	-11.9	-13.6	-13.8	-67.8	-17.0	-15.7	-15.7	-15.7	-15.5	-79.6	-14.74
6	-19.8	-14.8	-13.7	-14.5	-17.9	-80.7	-15.7	-14.6	-14.6	-16.4	-15.6	-76.9	-15.76
7	-10.5	-7.3	-8.6	-9.0	-10.6	-46.0	-7.2	-6.1	-7.5	-7.1	-7.9	-35.8	-8.18
8	-8.2	-3.2	-3.7	-3.8	-7.2	-26.1	-3.1	-3.4	-4.0	-4.3	-4.8	-19.6	-4.57
9	-4.5	-1.7	-2.0	-2.0	-4.2	-14.4	-1.6	-1.3	-2.4	-1.6	-3.8	-10.7	-2.51
10	-1.5	+0.3	-0.9	-0.5	-0.2	-2.8	+0.5	+0.6	+0.9	+0.8	-0.2	+2.6	-0.02
11	+0.7	+0.4	+0.8	+0.8	+0.8	+3.5	+1.1	+1.2	+1.0	+1.0	+0.6	+4.9	+0.84

*By impression number.

TABLE C-39

CHANGE IN PERCENT DOT AREA FROM FILM POSITIVE TO PRINT FOR 90° ANGLE

Gray Scale Step	Run 1* 2	16	22	25	40	Sum	Run 2* 7	14	23	32	38	Sum	$\bar{x}$
4	-4.6	-9.8	-12.4	-11.9	-11.9	-50.6	-13.2	-15.4	-16.5	-16.5	-15.8	-77.4	-12.80
5	-14.7	-11.7	-9.4	-11.1	-13.5	-60.4	-18.0	-17.6	-17.1	-16.3	-16.1	-85.1	-14.55
6	-17.7	-13.8	-11.9	-12.7	-15.2	-71.3	-16.2	-17.0	-15.4	-16.8	-16.0	-81.4	-15.27
7	-13.1	-8.3	-7.3	-8.5	-9.5	-46.7	-9.1	-6.2	-7.7	-7.3	-7.3	-37.6	-8.43
8	-9.7	-6.6	-6.6	-5.0	-5.7	-33.6	-4.3	-4.1	-4.5	-3.7	-4.6	-21.2	-5.48
9	-6.5	-2.1	-3.3	-3.5	-5.2	-20.6	-2.4	-2.9	-2.5	-1.1	-1.7	-10.6	-3.12
10	-3.0	+0.8	-0.6	-1.4	-0.8	-5.0	+0.3	+0.7	+0.8	+0.9	+0.4	+3.1	-0.19
11	-0.4	+0.8	+1.1	+1.1	+0.6	+4.0	+1.1	+1.1	+0.6	+0.9	+1.1	+4.8	+0.88

*By impression number.

Appendix C

TABLE C-40

TWO-FACTOR ANOVA FOR CHANGE IN PERCENT DOT AREA

Position on Press Sheet:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Angle:	45°	72°	81°	15°	6°	69°	60°	0°	39°	22.5°	67.5°	51°	75°	9°	90°	30°	84°	18°	21°	$T_{i..}$
4.99-34.55	-12.87	-11.46	-12.76	-10.88	-10.55	-12.12	-12.62	-12.24	-12.25	-13.20	-13.28	-14.65	-11.77	-12.58	-10.12	-9.75	-11.60	-11.21	-12.61	
	-11.32	-8.74	-11.00	-8.15	-9.30	-9.27	-9.40	-12.53	-10.73	-13.12	-14.06	-15.89	-14.97	-12.16	-15.48	-11.66	-15.42	-13.19	-14.98	
	-24.19	-20.20	-23.76	-19.03	-19.05	-21.39	-22.02	-24.77	-22.98	-26.32	-27.34	-30.54	-26.74	-24.74	-25.50	-20.41	-27.02	-24.40	-27.59	-457.99
34.55-64.55	-14.44	-10.29	-10.32	-6.10	-7.43	-12.28	-12.56	-10.57	-16.11	-14.75	-15.74	-14.02	-13.14	-9.55	-12.08	-10.29	-13.56	-12.21	-13.52	
	-16.25	-16.43	-15.86	-12.36	-14.30	-12.36	-15.48	-15.67	-16.25	-17.25	-17.32	-16.52	-16.30	-16.56	-17.02	-14.68	-15.92	-16.65	-16.09	
	-30.69	-26.72	-26.18	-18.46	-21.73	-24.64	-28.04	-26.24	-32.36	-32.00	-33.06	-30.54	-29.44	-26.11	-29.10	-24.97	-29.48	-28.86	-29.61	-528.13
64.55-94.55	-7.50	-5.53	-6.68	-5.46	-6.95	-9.56	-7.96	-5.54	-9.23	-8.42	-8.97	-7.75	-7.34	-8.00	-8.61	-7.30	-8.36	-8.67	-8.78	
	-8.29	-6.75	-7.88	-7.19	-6.74	-7.75	-7.57	-7.26	-7.74	-7.37	-8.16	-8.21	-7.96	-6.63	-7.54	-6.49	-7.15	-7.68	-7.31	
	-15.79	-12.27	-14.56	-12.65	-13.69	-17.31	-15.53	-12.80	-16.97	-15.79	-17.12	-15.96	-15.30	-14.63	-16.15	-13.79	-15.51	-16.35	-16.18	-288.35
$T_{.j.}$	-70.67	-59.19	-64.50	-50.14	-54.47	-63.34	-65.59	-63.81	-72.31	-74.11	-77.52	-77.04	-71.48	-65.48	-70.75	-59.17	-72.01	-69.61	-73.38	-1,274.47

APPENDIX C

TABLE C-41

Average Loss in Percent Dot area for Factors

"Image Angle" and "Tonal Value"

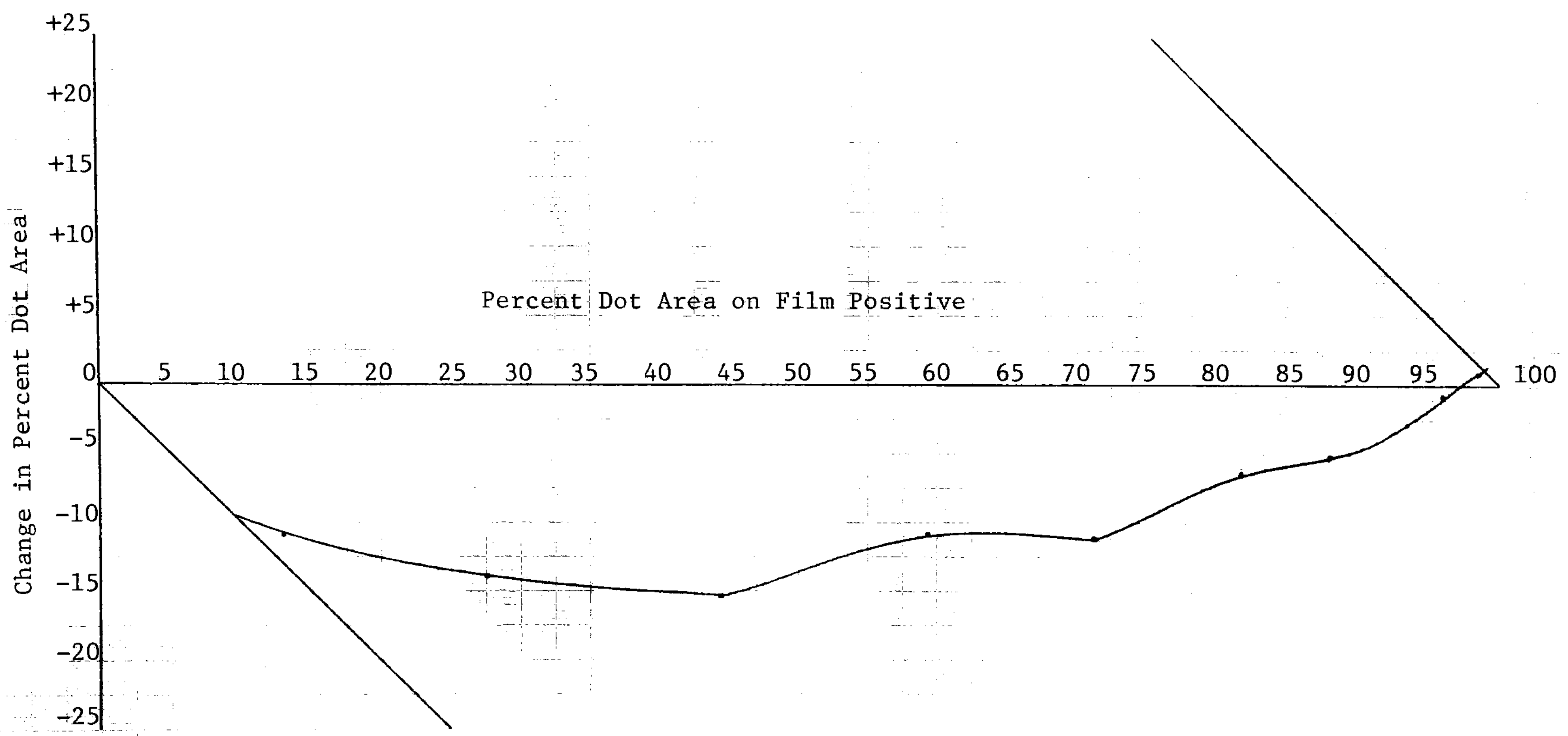
Angle (in degrees)	Average Loss
67.5	-12.92
51	-12.84
22.5	-12.35
21	-12.23
39	-12.05
84	-12.00
75	-11.91
90	-11.79
45	-11.78
18	-11.60
60	-10.93
9	-10.91
81	-10.75
0	-10.64
69	-10.56
72	-9.87
30	-9.86
6	-9.08
15	-8.36

Tonal Value	Average Loss
Middletones	-13.90
Highlight	-12.05
Shadows	-7.59

APPENDIX D

FIGURE D-1

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 0° ANGLE



Appendix D

FIGURE D-2

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 6° ANGLE

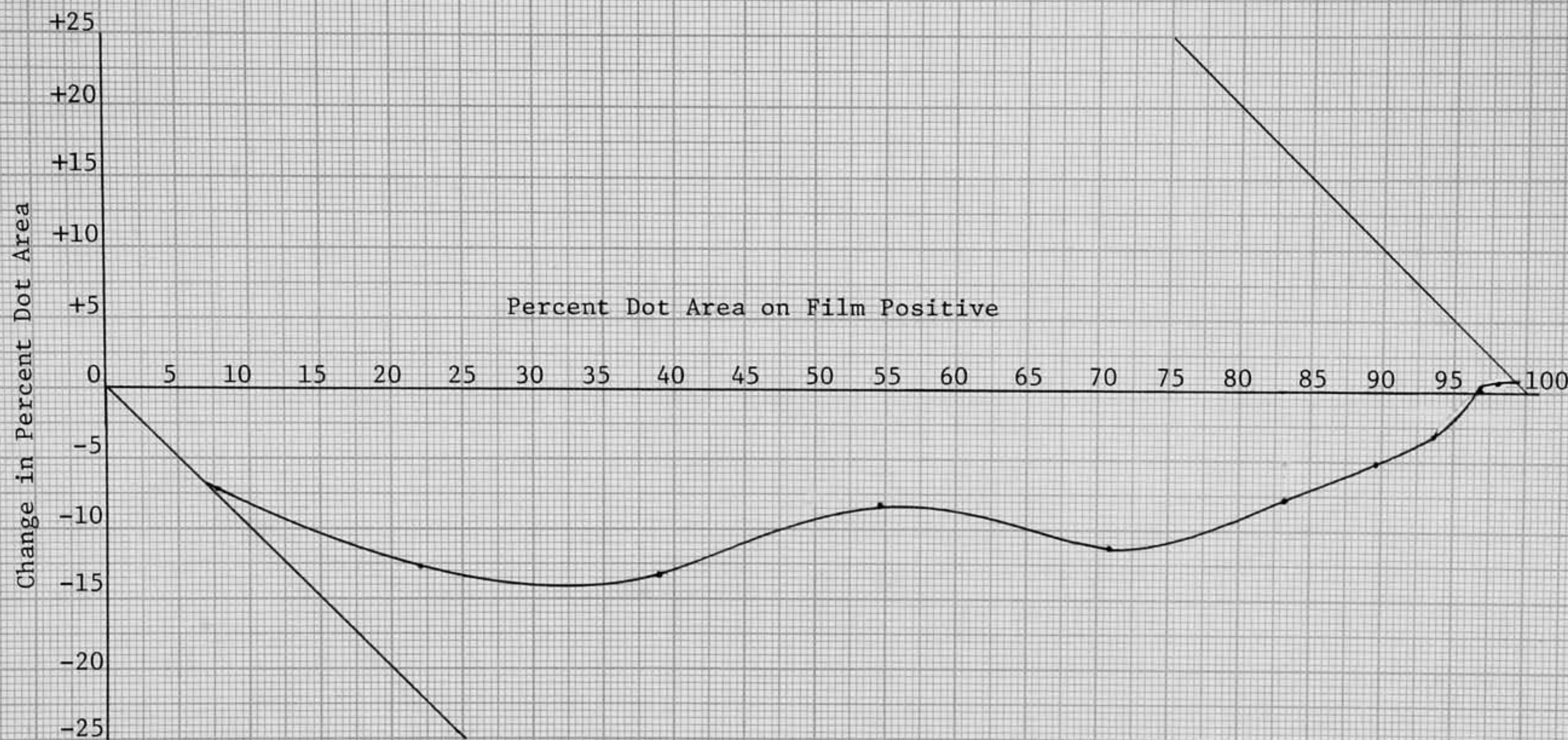
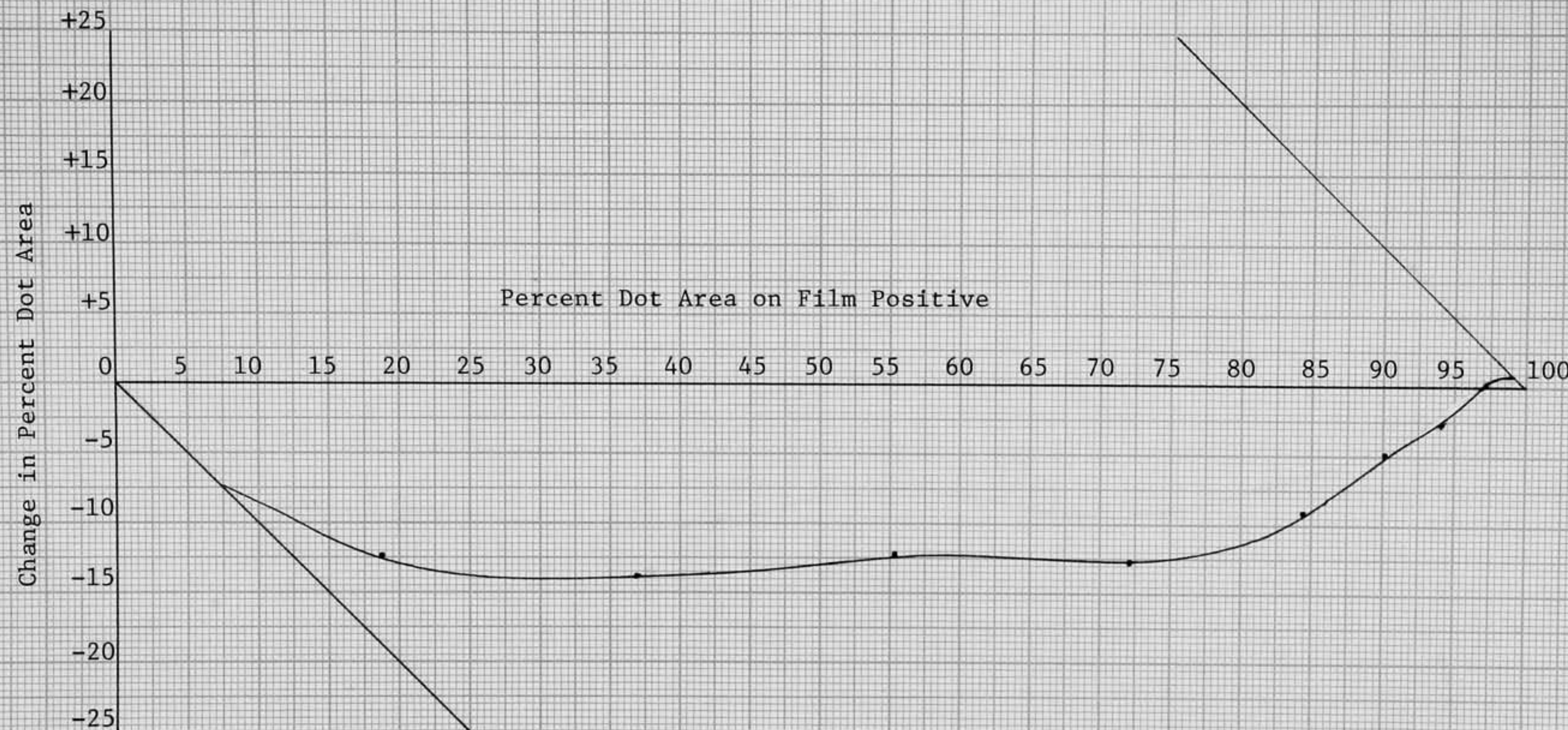


FIGURE D-3

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 9° ANGLE



Appendix D

FIGURE D-4

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 15° ANGLE

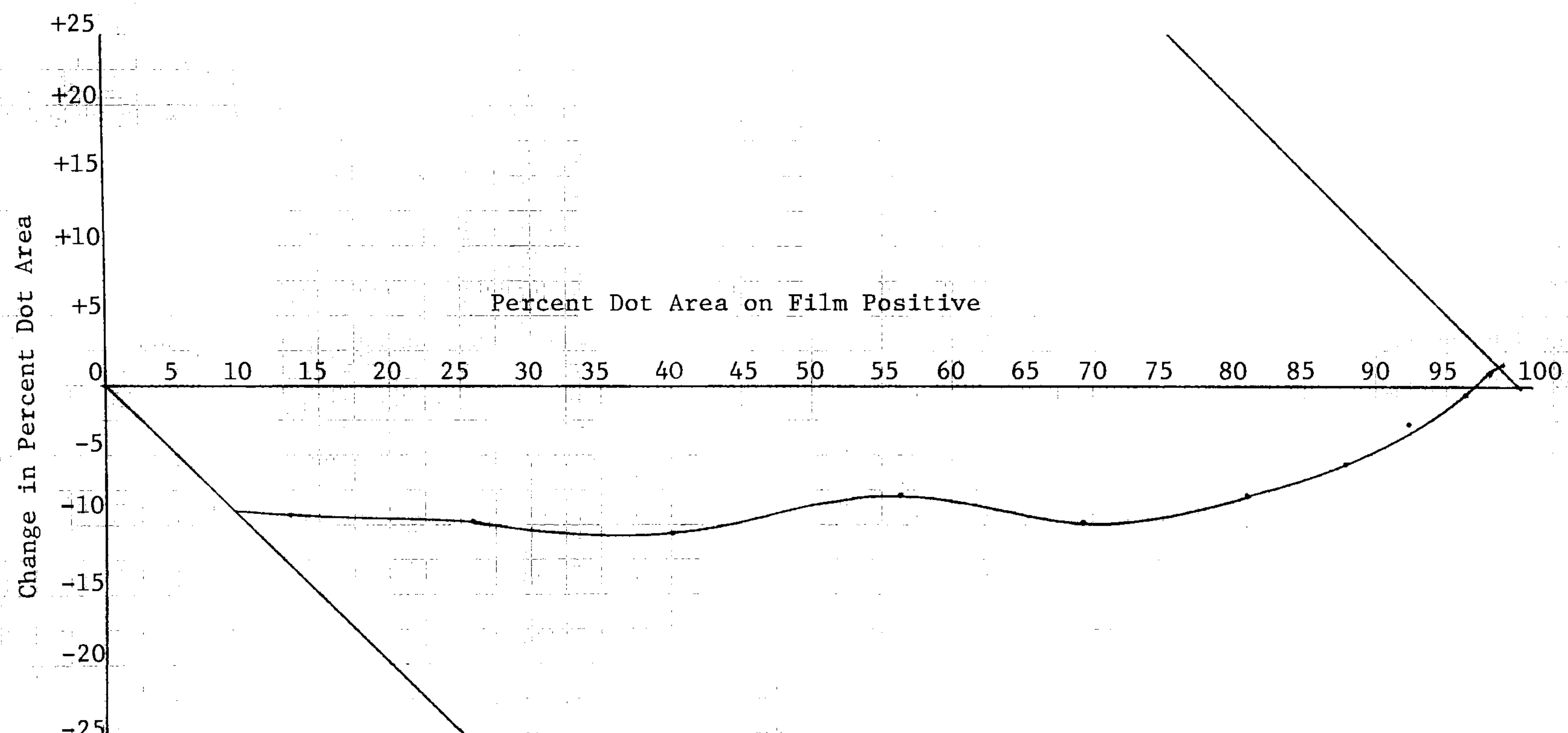
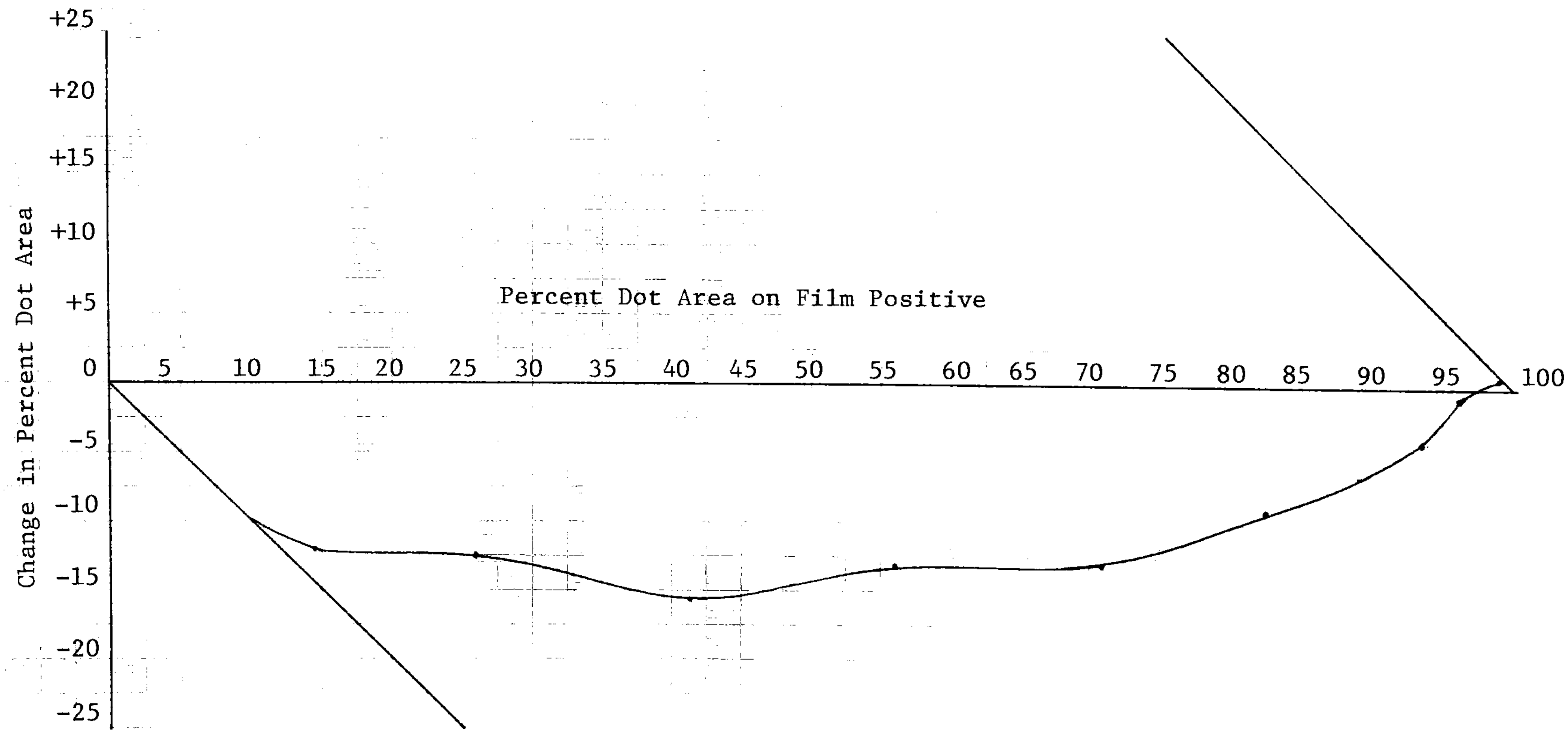


FIGURE D-5

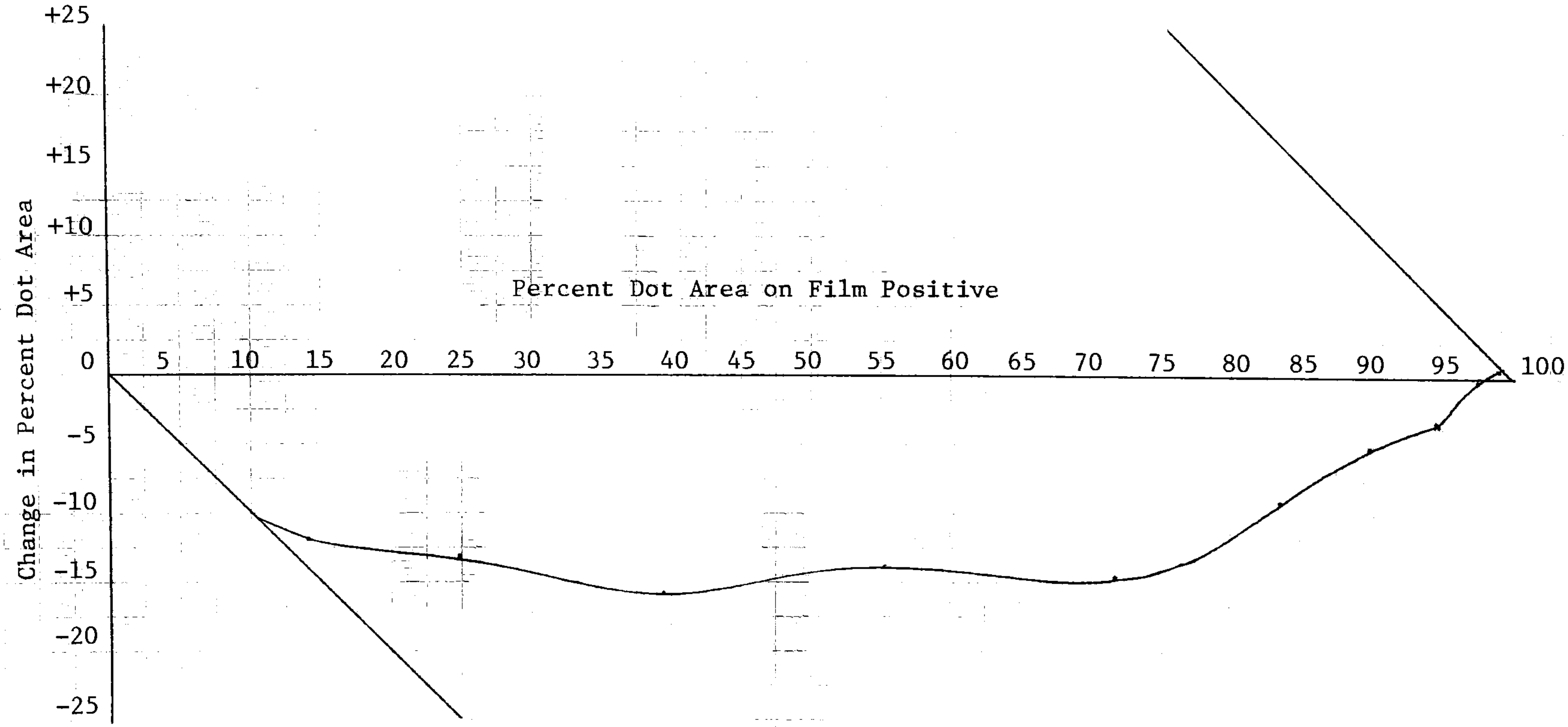
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 18° ANGLE



Appendix D

FIGURE D-6

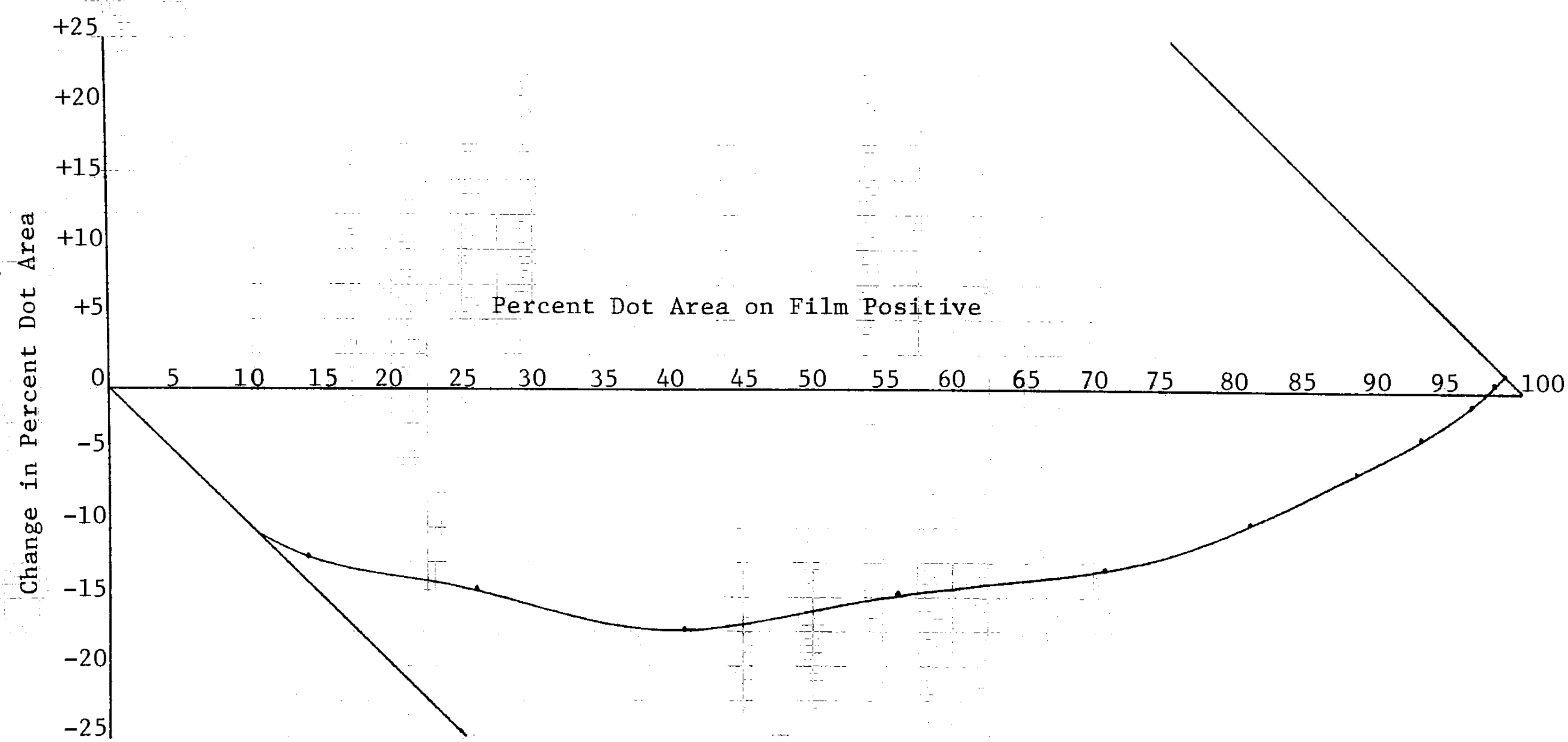
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 21° ANGLE



Appendix D

FIGURE D-7

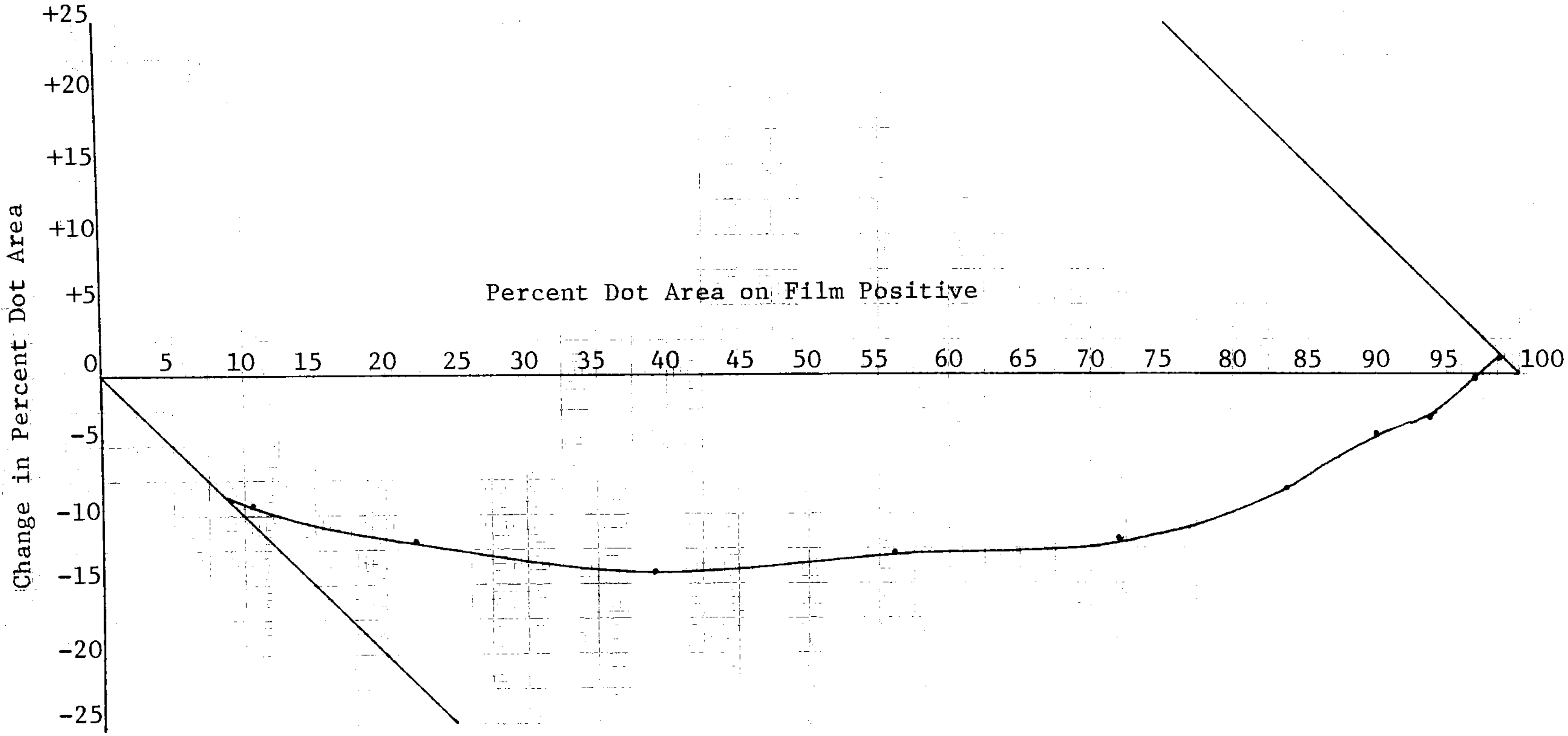
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 22.5° ANGLE



Appendix D

FIBURE D-8

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 30° ANGLE



Appendix D

FIGURE D-9

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 39° ANGLE

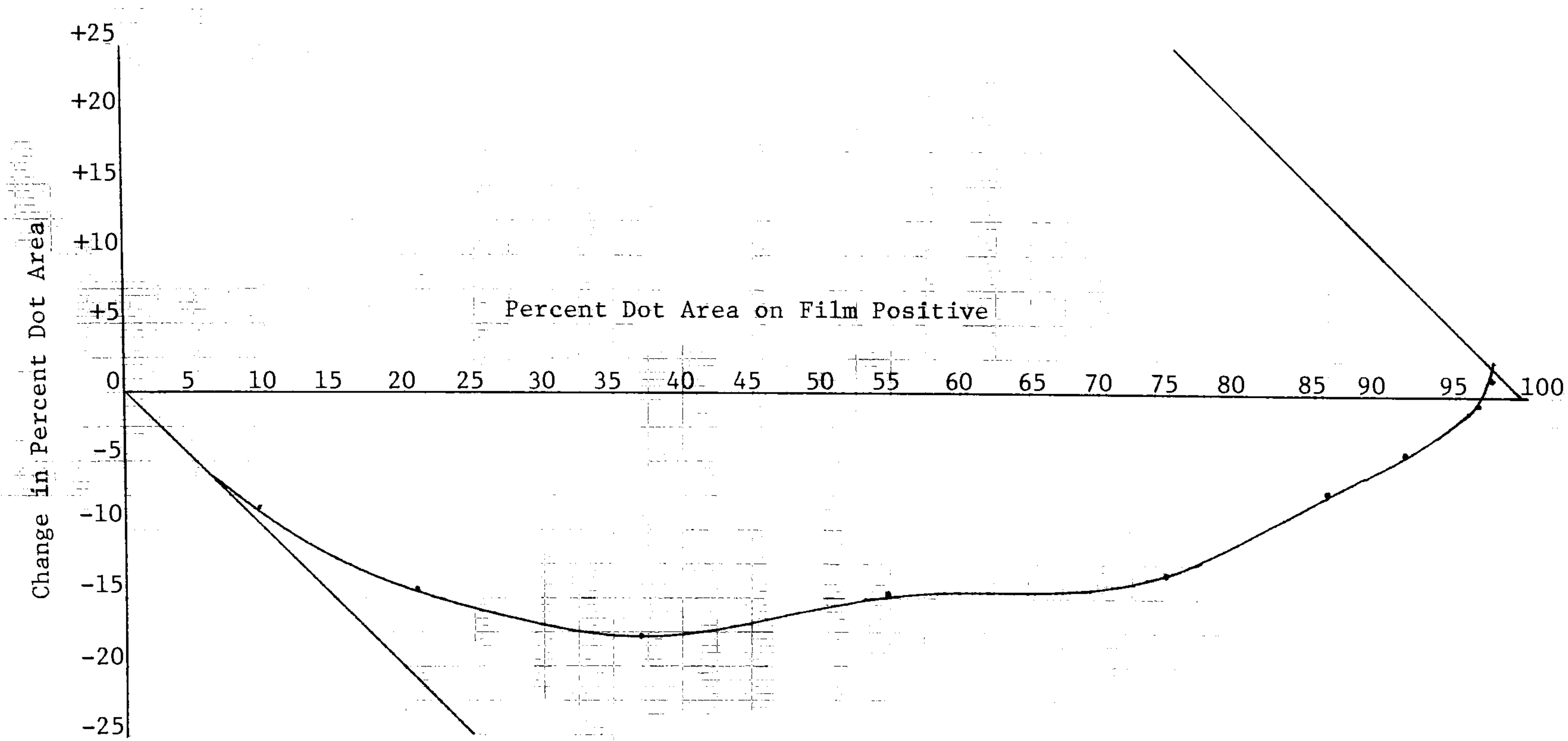
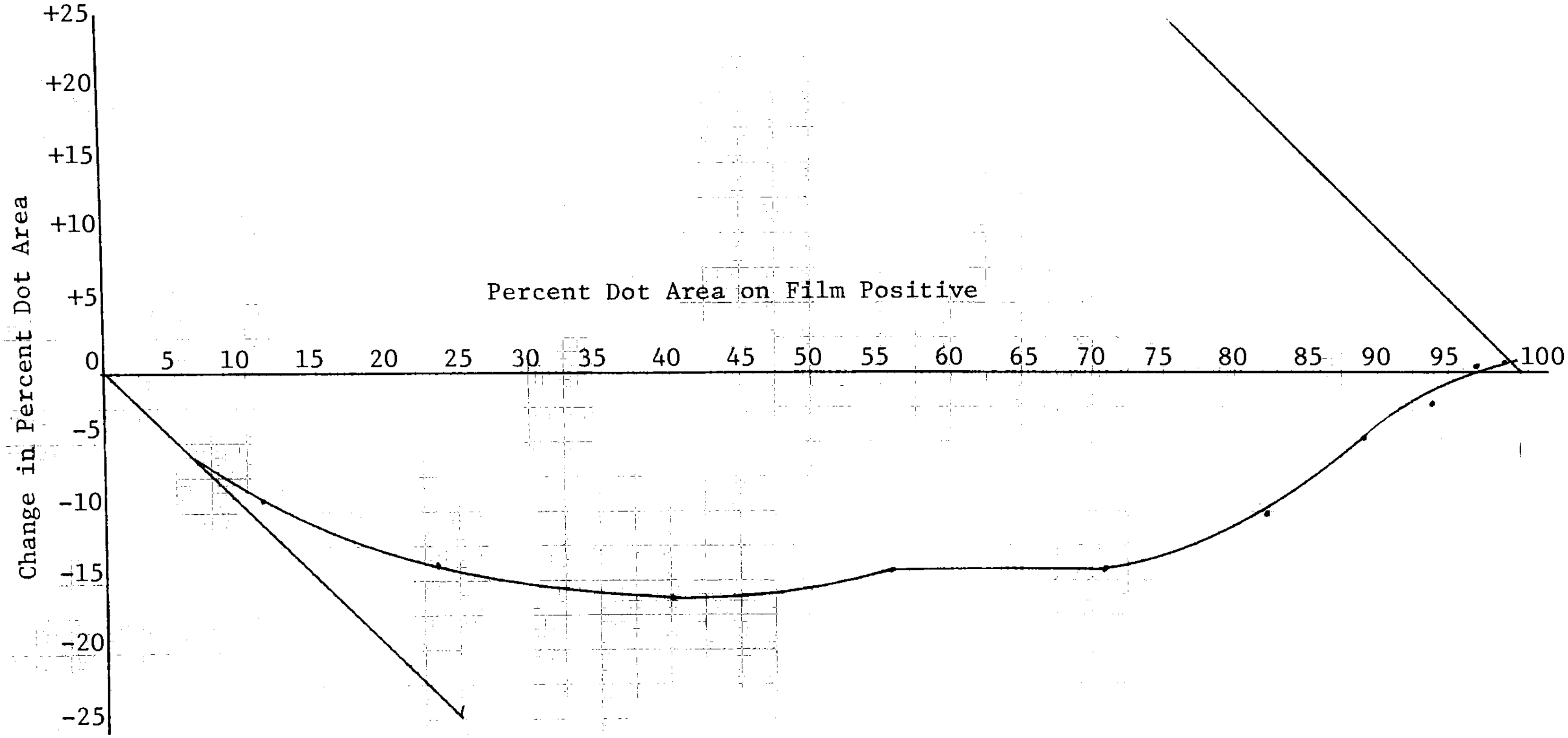


FIGURE D-10

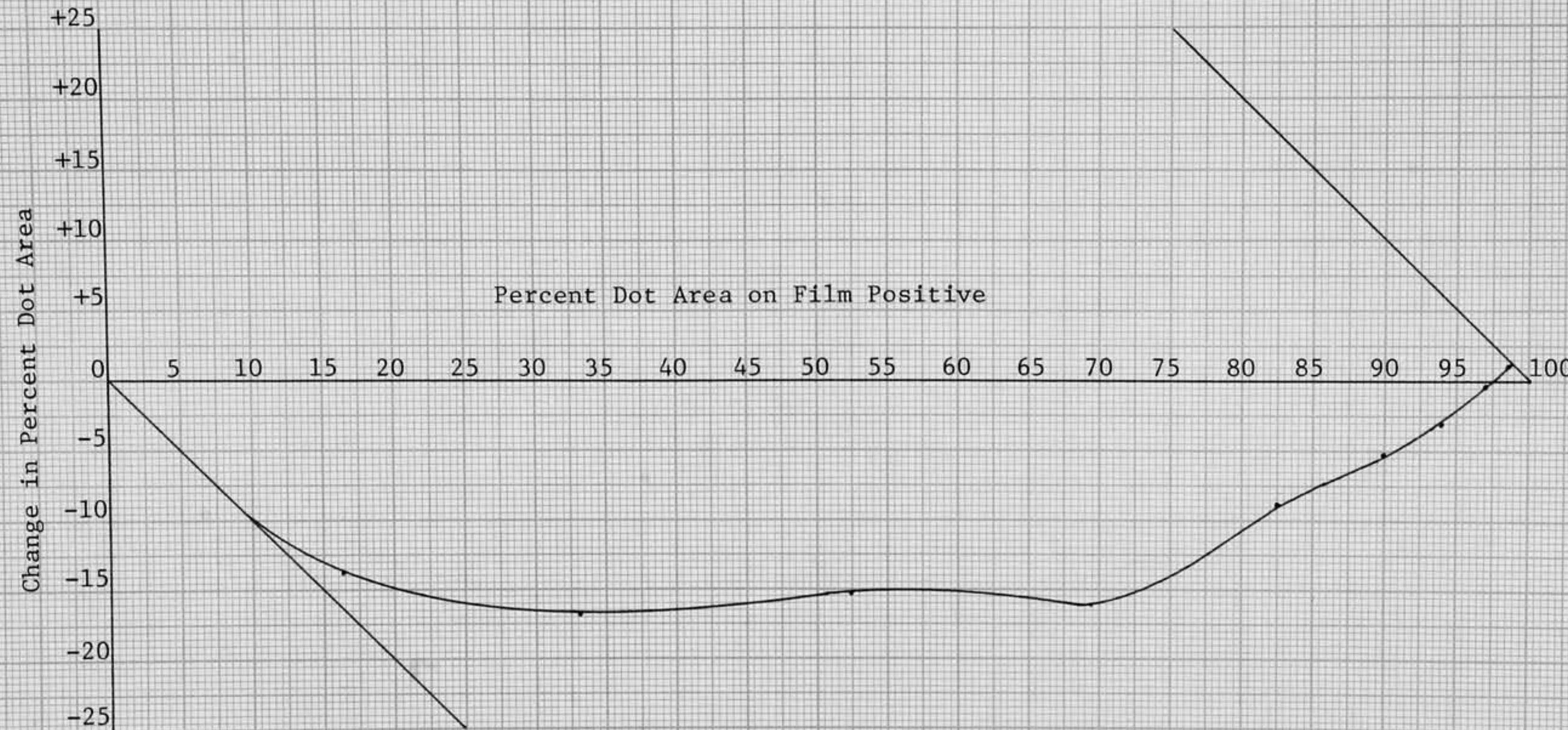
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 45° ANGLE



Appendix D

FIGURE D-11

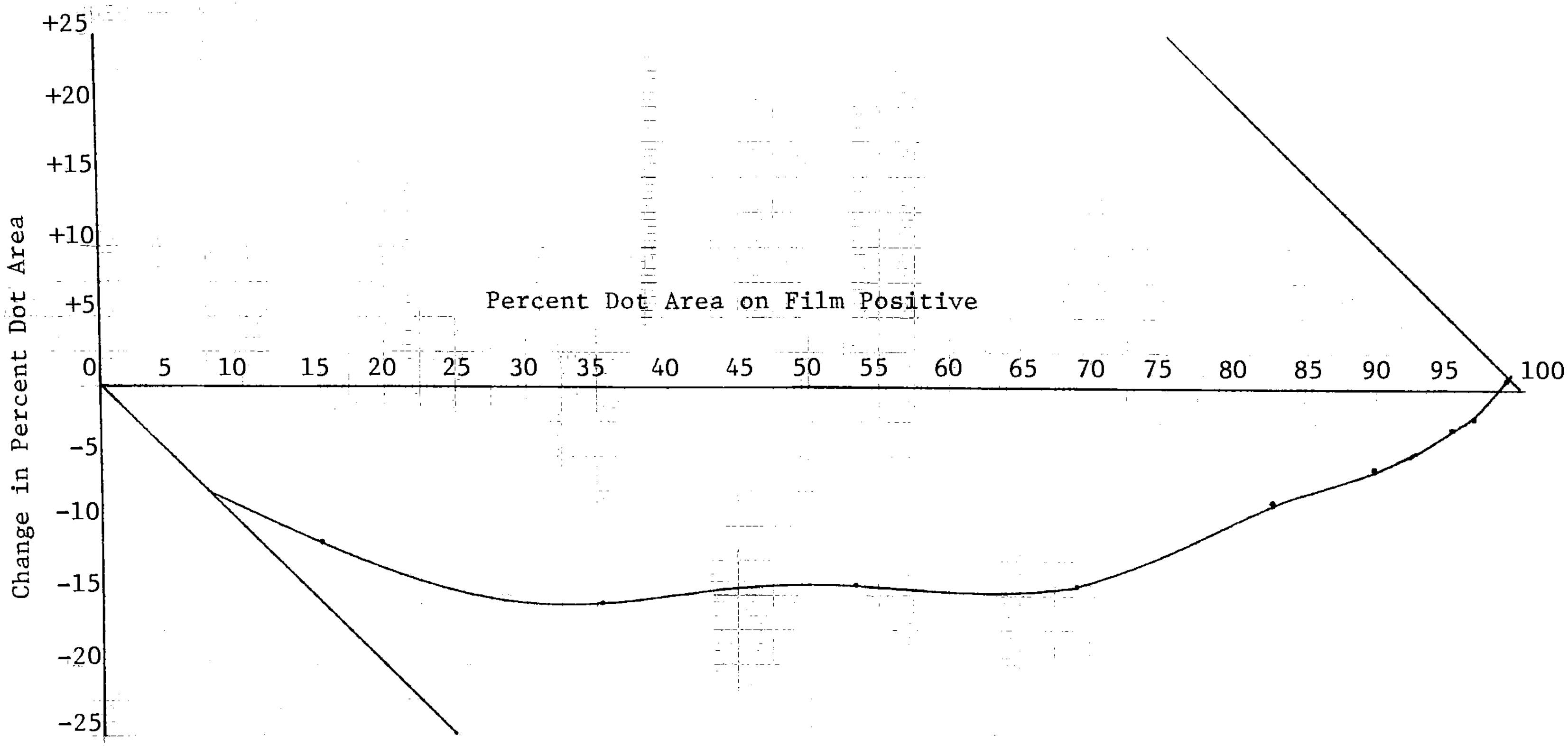
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 51° ANGLE



Appendix D

FIGURE D-12

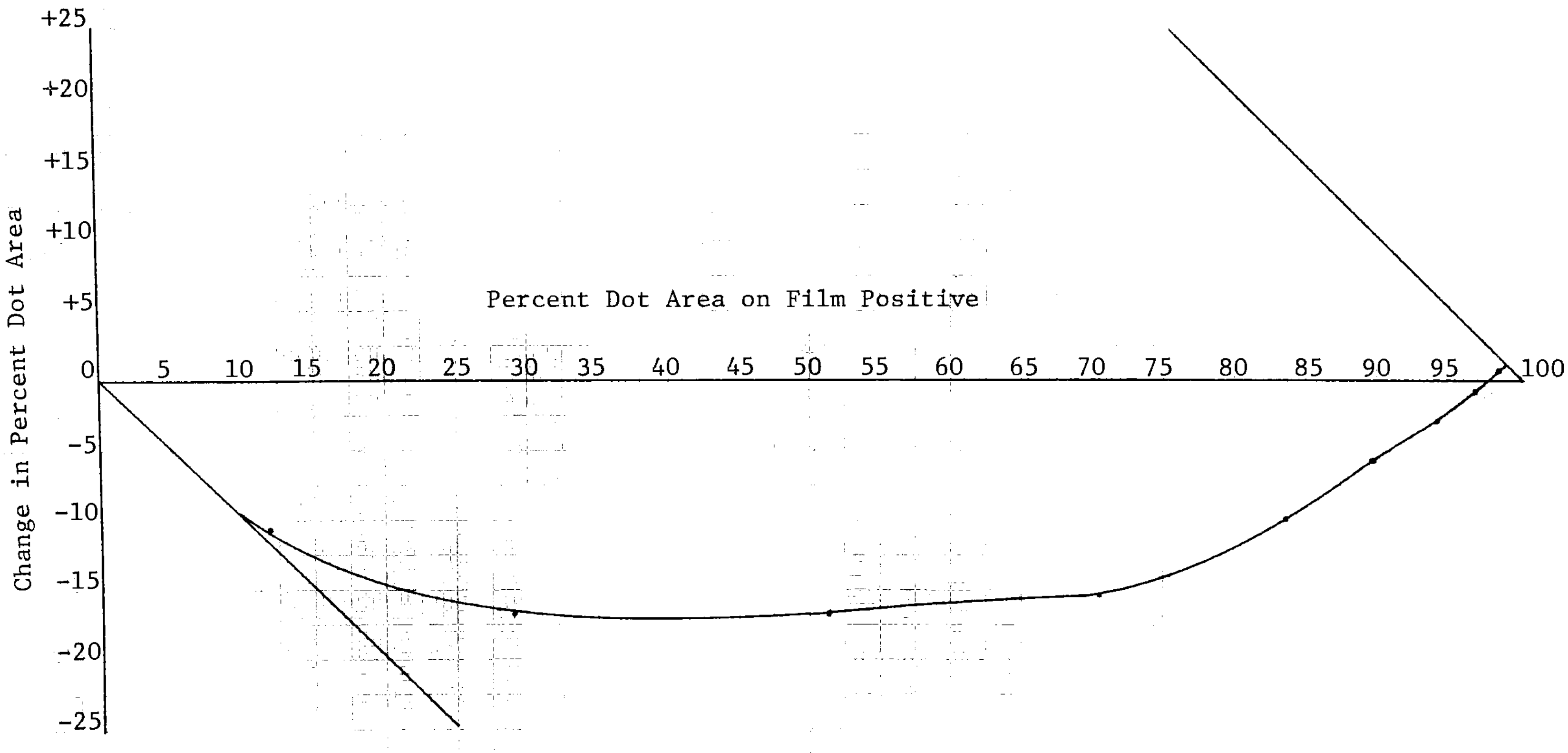
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 60° ANGLE



Appendix D

FIGURE D-13

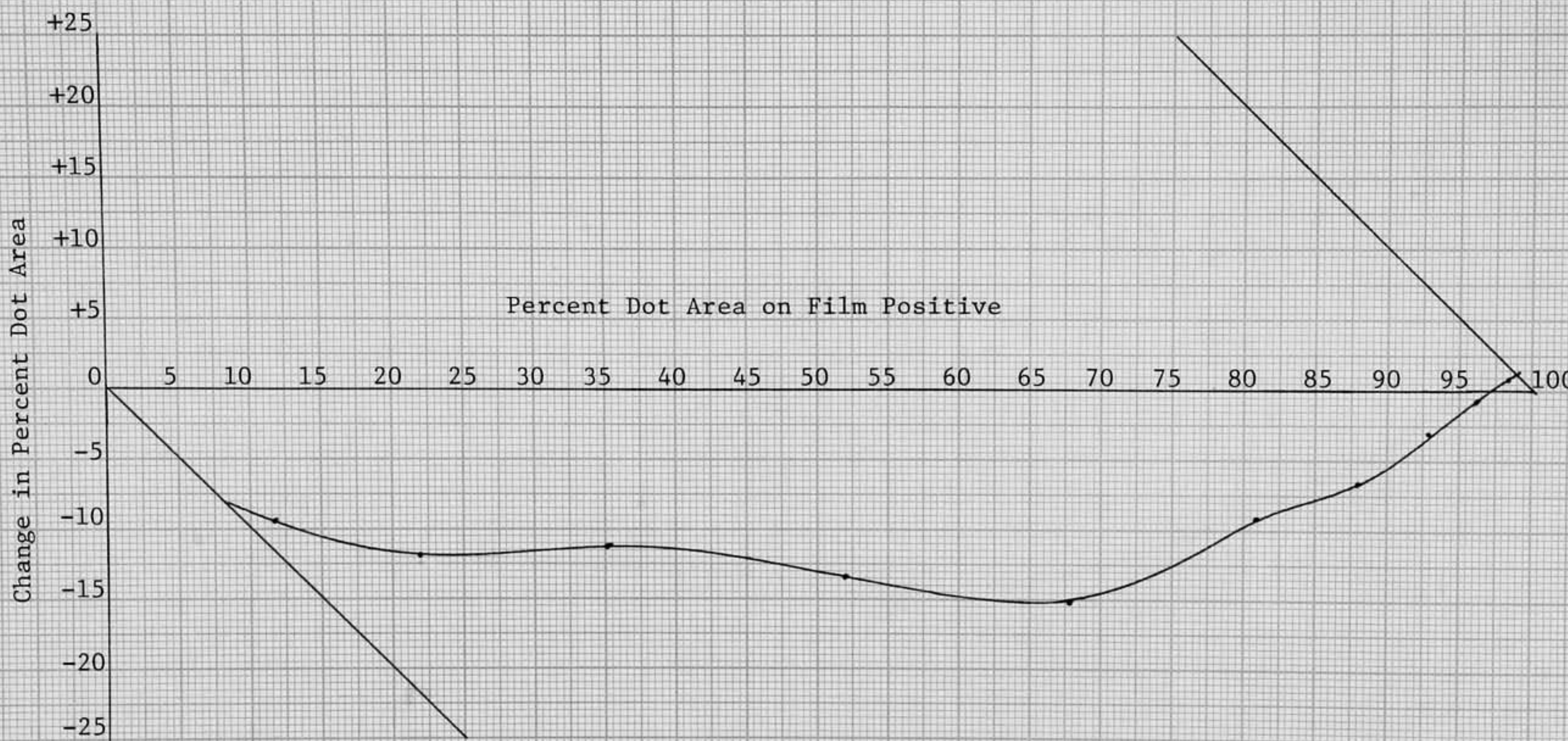
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 67.5° ANGLE



Appendix D

FIGURE D-14

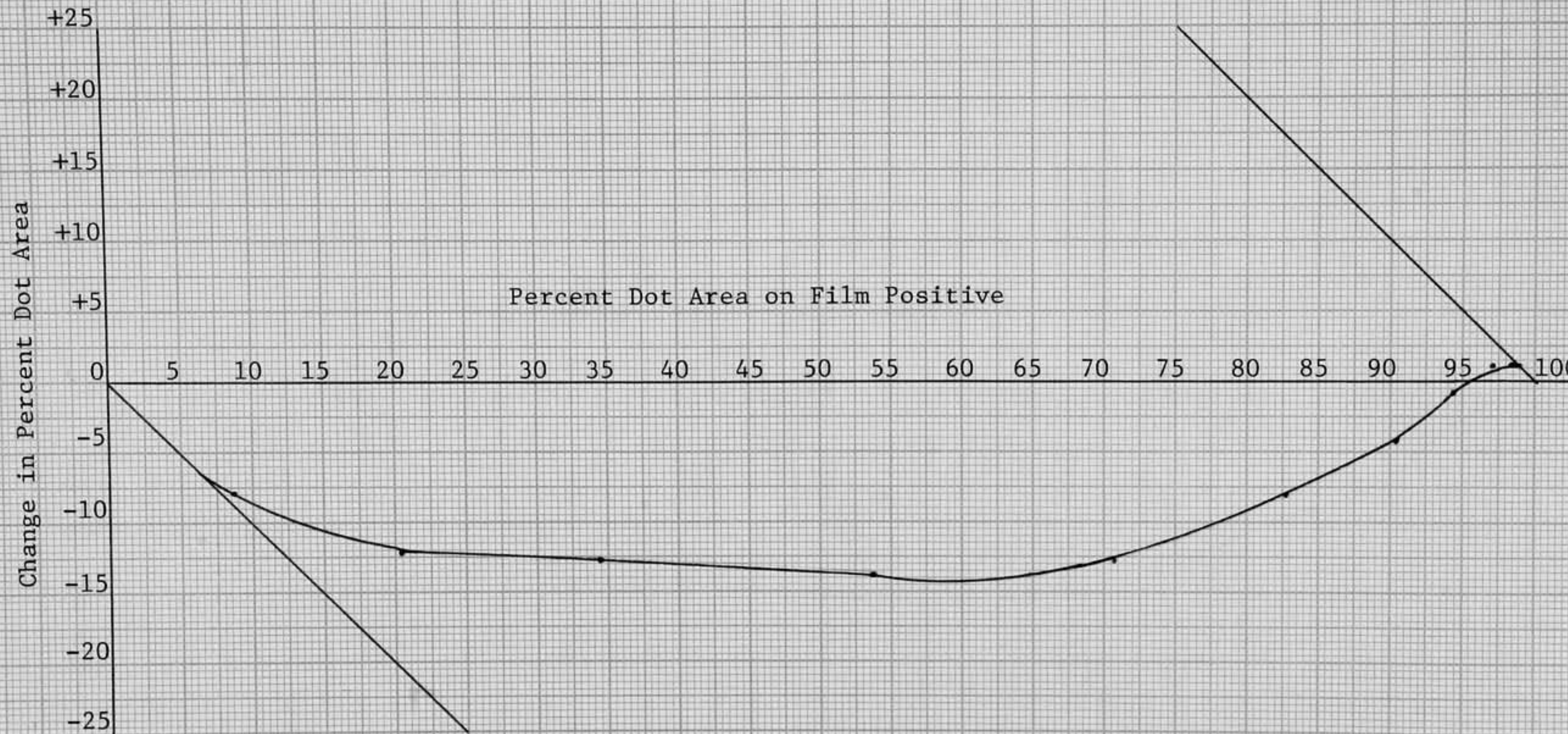
CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 69° ANGLE



Appendix D

FIGURE D-15

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 72° ANGLE



Appendix D

FIGURE D-16

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 75° ANGLE

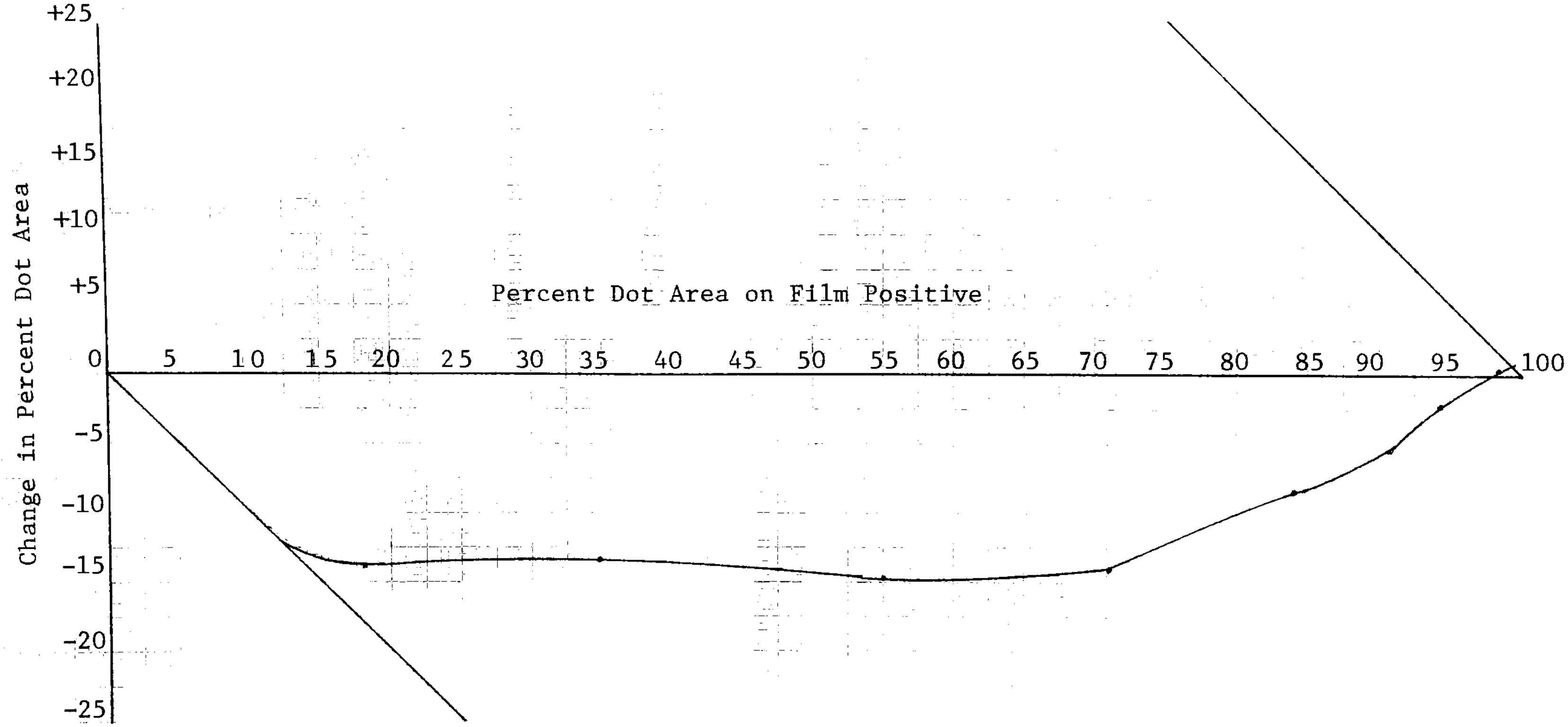


FIGURE D-17

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 81° ANGLE

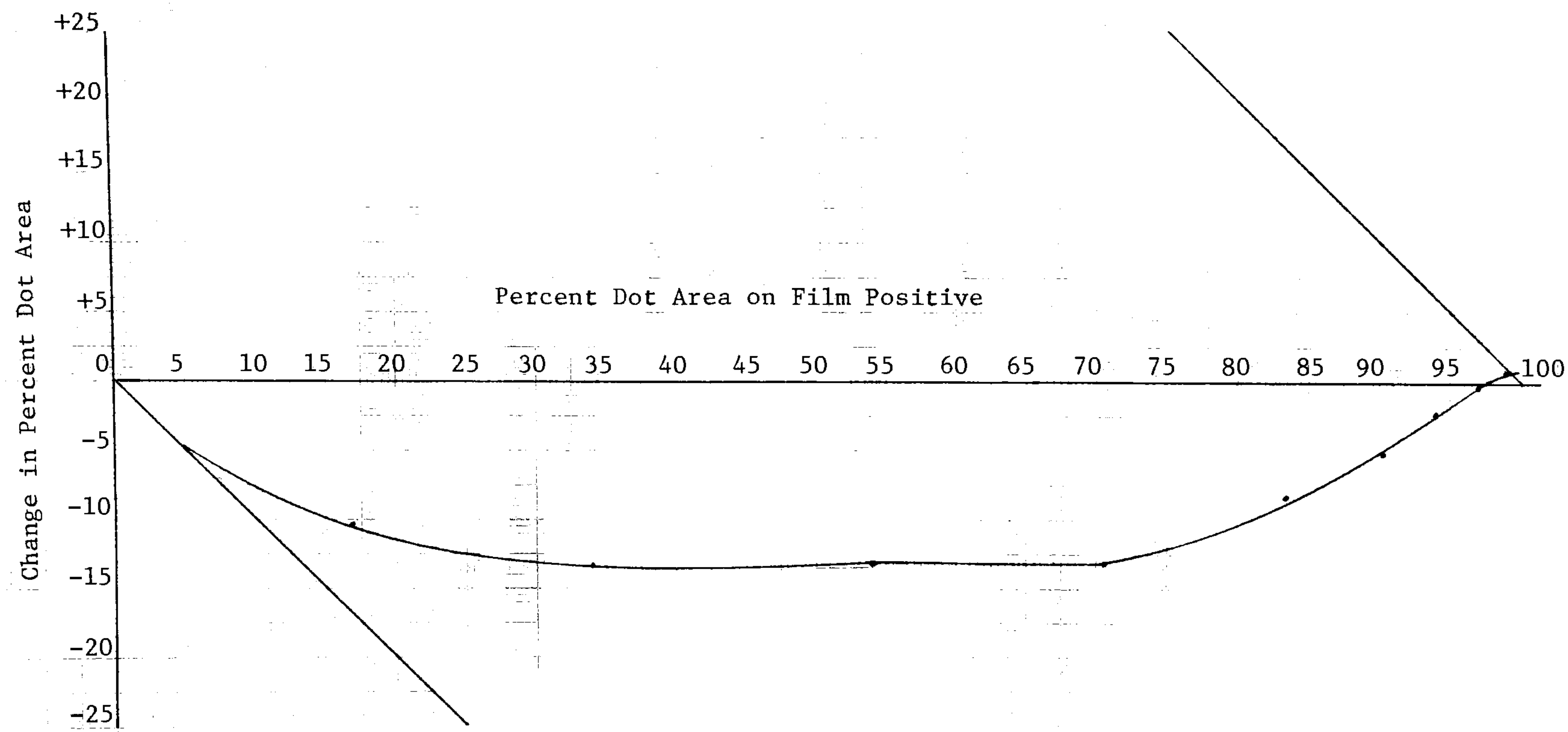


FIGURE D-18

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 84° ANGLE

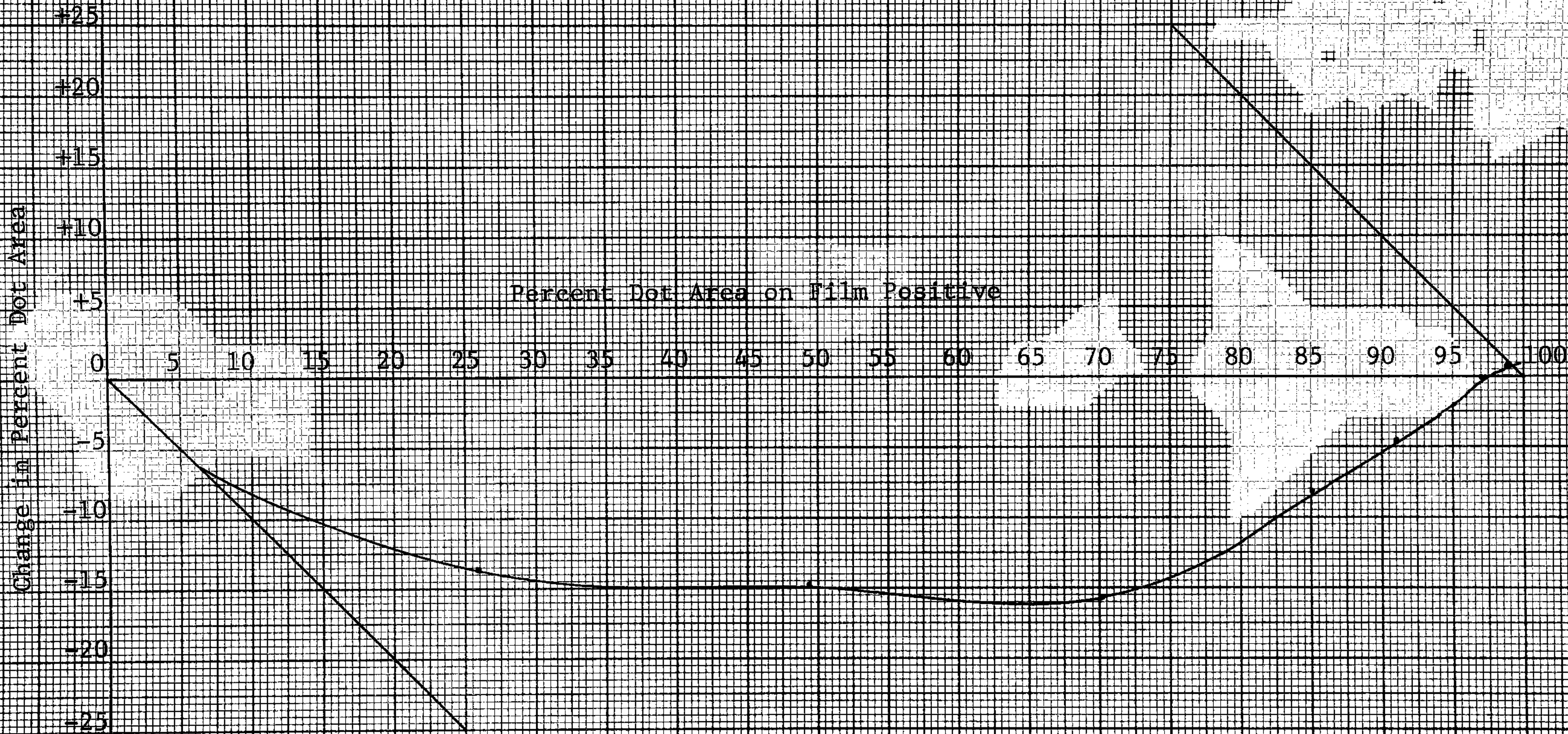
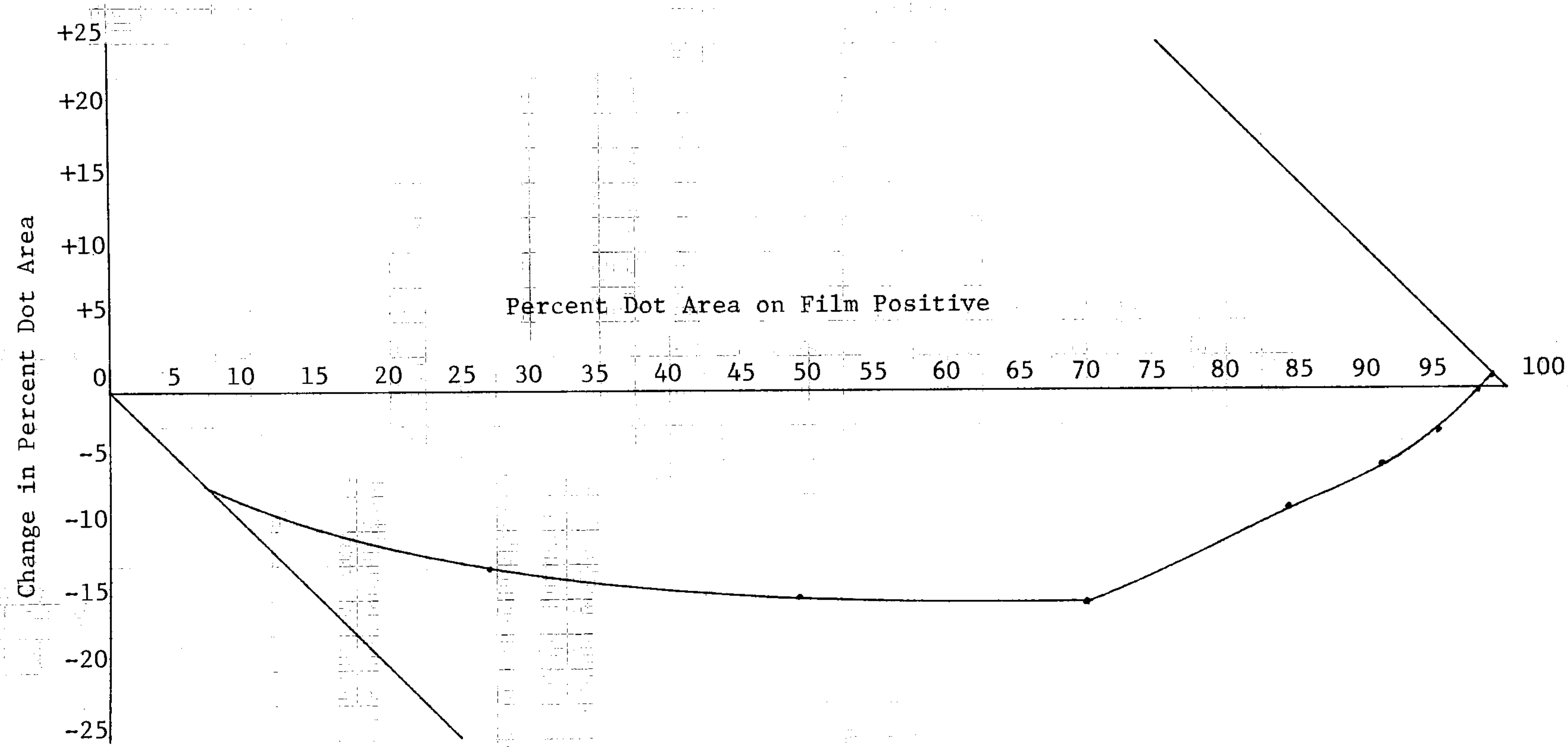


FIGURE D-19

CHANGE IN PERCENT DOT AREA AS A FUNCTION OF PERCENT DOT AREA ON FILM POSITIVE FOR 90° ANGLE



APPENDIX D

TABLE D-1

Tonal Range for Image Angles

Angle (in degrees)	Tonal Range
81	94.00
45	92.75
84	92.50
72	92.50
6	92.50
90	92.00
39	91.75
60	91.50
9	91.50
69	90.50
30	90.00
15	89.75
0	89.50
67.5	89.25
51	89.25
18	89.00
21	88.50
22.5	88.25
75	87.25